**Conservation Handbook Al Zubarah Archaeological Site**

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*Publication date:*
2013

*Document version*
Publisher's PDF, also known as Version of record

*Citation for published version (APA):*
Ricca, S., Sobott, R., Kinzel, M., & Hofmann, P. (2013). *Conservation Handbook Al Zubarah Archaeological Site*. (1 ed.) Institut for Tværkulturelle og Regionale Studier.

# CONSERVATION HANDBOOK
## AL ZUBARAH ARCHAEOLOGICAL SITE

**Edited by**
**Moritz Kinzel**
with contributions by
Paul Hofmann, Simone Ricca, and Robert Sobott
**QIAH-01-02-HE-1000**
**First Edition January 2013**

QATAR ISLAMIC ARCHAEOLOGY AND HERITAGE PROJECT
مشروع قطر لعلم الآثار و التراث الإسلامي
Heritage | Archaeology | History | Environment

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Edited by Moritz Kinzel with contributions by Simone Ricca, Paul Hofmann and Robert Sobott.
First Edition January 2013 QIAH-01-02-HE-1000. DOHA /COPENHAGEN 2013
ISBN 978-87-89221-08-3
Carsten Niebuhr Centre for Multicultural Heritage
Materiality in Islamic Research Initiative
Department of Cross-Cultural and Regional Studies - ToRS
University of Copenhagen and the Qatar Museums Authority - Al Zubarah Archaeological Site.

Language editing: Emma Hetherington

**Acknowledgments**:

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## CONSERVATION HANDBOOK
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# FOREWORD

The protection and preservation of Qatar's heritage is of fundamental importance. At a time when our world is changing at an alarming rate we need to remain mindful of our past. For it is only through our understanding of the past that can we hope to improve our lives in the future.

This Handbook is about how we can protect, preserve and present the architectural remains of Al Zubarah. This is not only important for Qatari people but for people everywhere. The site provides us with a testimony of global trade and cosmo-political connections. The concepts and methods compiled here will provide the basis to preserve and maintain Al Zubarah's remains, so that we may continue to visit and experience the site in its true form.

Prof. Dr. Sultan Muhesen
Senior Advisor
Director of Archaeology and Heritage
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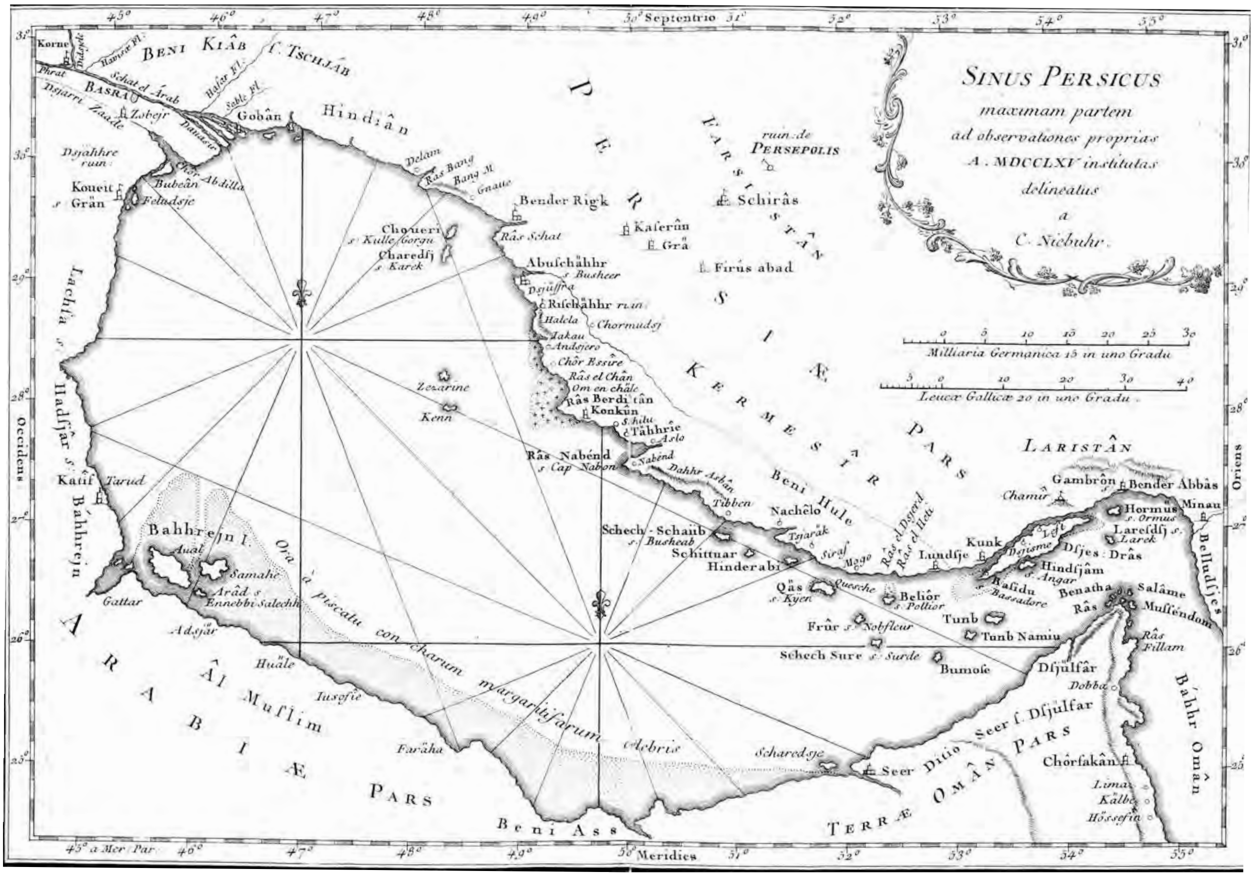



Carsten Niebuhr's map from 1765 mentioning "Gattar".

# INTRODUCTION

## HOW TO USE THIS CONSERVATION HANDBOOK

Since we started work on the conservation concept for Al Zubarah Archaeological Site there has been a tendency to reduce the information to a simple "user friendly" manual. As soon as we started compiling all the material related to the conservation and protection of Al Zubarah, however, we realised that a simple manual would not have the capacity to cover everything. This Handbook brings together all the existing information on the site. This includes information from site reports and archive material. It also makes the information more easily accessible to people involved in the conservation process.

The collection phase of the data also made it clear that different groups are involved in the conservation process of Al Zubarah and each of these needs to be addressed. These are groups both within the Qatar Islamic Archaeology and Heritage Project (QIAH) and within the Qatar Museum Authority (QMA).

The Handbook provides guidelines for the conservation and consolidation of architectural remains at Al Zubarah Archaeological site. It will be modified and updated according to the evaluation of regular monitoring and the assessment of executed works, in coordination with the QMA, QIAH experts, the crafts persons, conservation architects and international consultants. Notably, the section on ***fiches techniques*** will be expanded over time, with input by conservation craft persons and restorers and their on-site experience.

The Handbook has been structured into four main parts:

**PART 1 Basics**:
compiles available information on (building) materials and its deterioration patterns, as well as environmental conditions. It also provides also general introductions to the regional architecture, building terminology, and references.

**PART 2 Conservation Concept**:
introduces to the conservation concept and explains general solutions with "do and don't" case studies to provide guidelines for conservation supervisors.

**PART 3 Conservation Manual**:
contains ***fiches techniques*** detailing specific technical solutions for the conservation works presented in a simple and easy-to-understand manner designed for the craftsmen and the workers. The information and instructions presented in the fiches will help the workers in the execution of the work. However, a case-by-case decision on-site by the supervisor is ***always*** necessary.

**PART 4 Appendices**:
provides comprehensive additional information, reports, analyses, templates, and manuals as well as conservation schemes for specific areas at Al Zubarah Archaeological Site.

Moritz Kinzel
København, September 2012

# I. PREFACE

The Preface outlines the scope of the Conservation Handbook. It introduces the concept of "conservation of ruins" and identifies the visionary strategy for all concerned parties. Part Two of the Handbook reviews the overall philosophic approach to the conservation of Al Zubarah, building upon the recent evolution of the conservation theory for earthen architecture.

## I.1 Conservation Handbook

This Handbook is built upon a shared vision for the future of the site, which is the result of a common perception of both the archaeologists in charge of the excavation and the heritage and conservation teams. Input from laboratories, craftsmen and conservation architects are included to make the proposed strategy and the technical fiches realistic and technically sound.

The Handbook is a tool to guide the activities and direct the work on site, setting a series of principles and techniques that can be applied in a "mechanical" and "standard" way by technicians and workers.

It presents a series of "cases" and proposes, through simple "***technical fiches***", practical solutions for the teams in charge of the conservation of the site. The effectiveness and the actual impact of these techniques on the site will be reviewed over time and the handbook will be regularly updated to take in these new techniques.

The manual aims to achieve a higher degree of uniformity in the solutions applied to the site and to avoid unsuitable, personal decisions by middle-qualified foremen and builders. It is expected that the handbook will play an important role in the coming years and it is hoped that it might become a scientific reference for the entire region, beyond Al Zubarah.

Excavation work in the 1980s at Al Zubarah (QMA2)

## I.2 Conservation of Ruins

Preserving Al Zubarah Archaeological Site is a titanic and almost impossible task. Indeed, the very idea of "preserving the ruins" is in itself both a technically controversial issue and a technical non-sense as we aim at "freezing" the decay, which has no specific significance or value but is simply the result of a combination of natural and man-made decay over time. Traditional approaches to the conservation of ruins ranges from the "*freezing*" of existing ruins to the almost complete re-construction of a site. Intermediate solutions range from the abstract "*plan-like*" reconstruction of walls to more "*romantic*" partial reconstructions of the ruins as "*more stable ruins*" or even as "*more ruin-like ruins*".

Though the concept of "*preserving ruins as ruins*" has a romantic touch, it is likely one of the most challenging in 21st century conservation. Al Zubarah archaeological site becomes, therefore, an extraordinary opportunity not only to test state-of-the-art techniques and methodologies, but also to reconsider the actual sense and scope of conservation and restoration of ruins from a conceptual point of view.

Our endeavour is an attempt to slow the rate of decay in a particularly harsh climatic environment. Therefore, our activity cannot be perfect or everlasting. Before we begin, we need to fully understand why we want to do this work, what it implies and what aims we hope to achieve. Aside from the essential scientific issues related to the selection of the materials and building techniques to accomplish this task, we need to consider the full scope of this project and its aesthetic and theoretical implications.

*What solution should be adopted for at Al Zubarah?*
At the technical level, "conservation of ruins" strictly overlaps with the concept of "***continuous maintenance"*** based upon a state-of-the-arts "monitoring" of the evolution of the site and of the vestiges. However, it is also more than that. Not only should we continuously remove dust and sand, clean and re-point, check and replace individual stones and preserve remaining plasters, but we should also fill in voids, partially reconstruct window sills and doorways, rebuild loose masonries, and replace entire rows of decayed stones with more resistant ones. We are not simply "*conserving*" and "*maintaining*" the remains but we are actually replacing, rebuilding and transforming the site. We are working at the edge of the traditional post Venice-Charter doctrine, not only on fragile remains, but also on a "fragile" scientific and theoretic ground.

*What principles should direct our actions?*
*What projected result are we looking for in two, five or twenty years?*
QIAH Project aims at achieving a certain level of coherence, clarity and sustainability in the conservation interventions. Original and restored colours, surfaces, masonries and plasters should be able to convey a clear and understandable message to visitors without leaving room for ambiguities and misinterpretations.

The QIAH team has set general principles for the project based notably on the driving concept that "***we want to preserve Al Zubarah, not to rebuild it***", in order to offer visitors, specialists and laymen alike the image of an authentic archaeological site and not of a superficial, reconstructed heritage village.

In a recent British publication[3] devoted to the conservation of ruins and archaeological sites, Gionata Rizzi, an Italian architect active in the conservation of archaeological sites in Europe and the Middle East, draws our attention to that:

*"There is no such intervention that satisfies all the criteria of an abstract idea of 'conservation correctness', that is irreproachable from a theoretical and a technical point of view: each site has a different story, each calls for a specific approach. In conserving a ruin, it is impossible to be neutral. Experience teaches that, no matter how cautiously the work is designed, a conserved ruin always bears the traces of the interventions carried out. But if one cannot be neutral, one can at least try to be elegant and effective."*

Rizzi also underlines the importance of the preliminary activities to be carried out on a site before launching the conservation works. This can help us in defining the principles guiding our intervention. According to his vision, the architect in charge of the project should have a profound knowledge of the architectural body he sets to conserve, of its built form, history and of past interventions. He should have a perfect insight into its structural behaviour, a solid understanding of the materials and a deep comprehension of the mechanisms of decay active on the site. In the case of Al Zubarah these elements have been taken into consideration and high-quality scientific information has been collected and produced by the QIAH teams excavating on-site since 2009.

The comprehensive studies and analyses carried out in past seasons by the archaeological and the conservation units of the QIAH project – a large group of highly qualified archaeologists, architects, scientists and technicians – has allowed us to reach an in-depth knowledge of the history of the site and of its evolution, and a clear understanding of technical (material) and aesthetic characteristics of Al Zubarah at the height of its occupation.

3 John Ashurst (ed.): Conservation of Ruins. London 2006.

State of conservation Al Zubarah (QMA2) in April 2012
(spherical photograph by K.Mechelke, HCU Hamburg)

Ongoing intensive archaeological research and excavations at the site have shed light upon the social, economic and ecological structure of Al Zubarah society in the late 18th and 19th centuries. Furthermore, excavations have uncovered previously unknown major architectural features and have recovered fragments of the wooden and gypsum decorative elements that composed the ornamentation of Zubarah's mansions, forts and houses. These elements, carefully collected, stored and documented, offer us a vivid glimpse of everyday life in this pearl fishermen's city.

The ambitious and comprehensive archaeological project launched by the Qatari authorities, with the scientific support of the University of Copenhagen, has allowed for a comprehensive survey of all archaeological sites along the Qatari northern coast and of the surviving traditional villages throughout the region, offering conservationists, archaeologists and visitors an invaluable comparative framework. Similarly, laboratory tests carried out in past seasons, and the tests carried out in situ on plasters and masonries, have enabled us to reach a good understanding of the physical, chemical and static issues typical of the ruins of the city of Al Zubarah.

Finally, the mechanisms of decay of the vestiges have also been investigated and understood, though more data on anhydride plasters and gypsum-based mortars still needs to be collected.

Likely, the only element partially missing in the vast documentation collected until now is the scientific analysis of the earlier conservation campaigns undertaken in Al Zubarah. This Preface explicitly deals with the subject, with the aim of identifying the theoretical framework of this earlier campaign and of assessing its actual impact on the physical remains.

## I.3 Past Interventions in Al Zubarah

### I.3.1 Historic Introduction

The ruins of Al Zubarah constitute not only the largest and most important Qatari archaeological site, but also the most complete and well-preserved pearl trading and diving town of the 18th-19th centuries. The site not only reflects the history of tribal migration in the Arabian Gulf (as it was founded by merchants arriving from Kuwait and Basra in the search for pearls), but also represents a unique mode of occupying a fragile desert ecosystem, which includes a particular system of water management.

During the mid to late 18th century, Al Zubarah was the Gulf's most important trading hub, connecting the Indian Ocean with Arabia and western Asia. The site highlights how trade and exchange connected people from East and West economically, socially and culturally, making Al Zubarah a non-European, traditional form of settlement encapsulating unique anthropological and social historical themes.The different components of Al Zubarah's urban plan show that the settlement was conceived and implemented from the outset. The layout of the town shows, therefore, both the sophistication of the planning principles, and the capacity of Al Zubarah's rulers to control and direct the social and economic forces driving the town's creation.

The site of Al Zubarah was mostly abandoned in the 19th century and it has been only briefly and partially reoccupied since then. The early abandonment of Al Zubarah at the beginning of the 20th century has helped to preserve the detailed urban layout of an 18th-19th century pearl fishing and trading town. Though some sectors were voluntarily destroyed in the 1970s (Qalat Murair), most of the decay within the area is the result of natural causes and of the restorations in the 1980s.

The site remained almost completely abandoned until the 1980s, when a major conservation campaign was launched. When considering the overall layout of the site, we should keep in mind that a significant percentage of what is currently visible at Al Zubarah is the result of that excavation campaign. These works were documented at the time by a publication[3] in Arabic and by some colour photos (collected by QIAH), although unfortunately no complete record of the intervention has been kept.

### I.3.2 The Cultural and Theoretical Framework of the1980's Campaign

The review of the large-scale works carried out in the 1980s underlines the strong impact of the theoretical choices that were made at the time. In order to define the new guidelines, we should not only focus on the mechanisms of decay of these earlier "restorations" but also identify the aims and implications of the conservation and presentation choices made at the time.

The team in charge of the works realised that it was impossible to uncover the ensemble of the city and opted for the definition of "priority areas". Therefore, the campaign in the 1980s focused on the external city wall, which was was extensively rebuilt with cement mortar and local stones, and on a series of punctual excavations, the so-called Northhouse (QMA2), the Suq area (QMA1), and the fortified Compound (QMA4).

3 Kholafi 1987

The 1980's campaign did not aim at reconstructing archaeological remains and none of the remaining structures was rebuilt to the original roof level. Similarly, no interior was "completed" to offer a more complete image of what the buildings used to look like, and no new structures to favour the visit were added to the ruins, even though relatively heavy work took place and significant reconstructions of partially collapsed walls and vaults were carried out.

The driving concept of the conservation and presentation works was to present a regular plan of the ruined structures, to make the remains more easily "understandable" for the visitors. Therefore, original walls were "completed" with the addition of courses of stone to reach this abstract level, while higher standing walls were simply "capped" with a layer of hard impermeable cement-based mortar (upon which often was added a final course of stone capped with a more visually-neutral white cement mortar) to reach a regular level permitting the "reading" of the architecture.

The 1980's project aimed at presenting Al Zubarah as an archaeological site and as a major consolidated ruin. The excavated areas were respectfully considered and treated to reach an abstract "*plan-like*" image underlining their "*archaeological*" significance and presenting them as "*timeless*" remains unearthed from the desert sand.




Excavation and Conservation work during the 1980s at Al Zubarah.

### I.3.3 A Preliminary Assessment of the 1980's Campaign

A scientific assessment of the 1980's campaign underlines three major issues:

1) From many points of view, the driving concepts upon which the campaign was based were "modern" and coherent. The approach is notably at odds with plans that blur the line between "original" and "reconstruction", aiming to transform archaeological sites into a pastiche "heritage" site.

2) Unfortunately, however, while the "theoretical" approach still seems scientifically correct (other tougher options for the presentation of the ruins might have been made), the quality of the technical work on the original masonries and plasters did not meet the same standards. The reliance upon strong modern building materials for mortars and masonries (cement capping and harder stones were regularly used for the added layers with a dramatic impact on the overall stability of the walls that were "restored") on the one side, and an overall misunderstanding of the decay mechanisms of the original masonries after their excavation on the other, have led to a dramatically increased rate of decay not only of the additions in the 1980s, but also — and mainly — of the "original" parts of the structures.

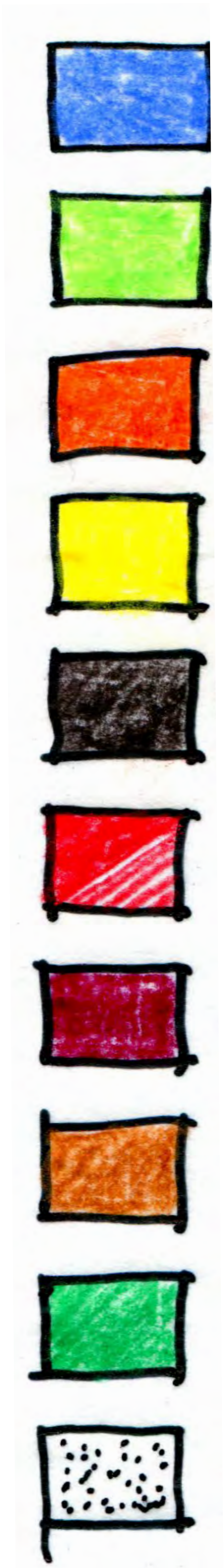
3) The second major lesson to be learned from the 1980's experience is that no single "once and for all" campaign can reach a long-lasting impact on such a vast and complex archaeological site. The evident decay of the areas "restored" in the 1980s has been further accelerated by the absence of regular maintenance at the site once the campaign was over. The 1980's project lacked a long-term strategy and management guidelines and mechanisms for guaranteeing its sustainability.

Furthermore, the 1980's campaign did not have a "***vision***" for the ensemble of the city. It focused solely on punctual elements, without proposing a comprehensive strategy for the entire site. Conservation works dealt exclusively with the areas that were uncovered and it never tackled the ensemble of the city. No comprehensive plan for conservation and presentation was ever drawn.

Simone Ricca, December 2012

State of conservation Al Zubarah (QMA1) in the 1980s after the first consolidation work.


ACTION PLAN (2011 to 2016)
for Initial Consolidation work
(without regular maintenance work)
spring 2011
2011 / 2012
2012 / 2013
2013 / 2014
2014 / 2015
2015 / 2016
after 2016



Historic building stones
(mainly beach rock)

Aeolianite (mainly 1980s repairs)

"Original" historic wall and floor-
plaster (anhydrite or lime-based)

1980s cement

Historic wall mortars

QIAH-repairs (stones)

new plaster (QIAH)
(at the moment lime-based)

new wall mortar (QIAH)

Plaster (surfaces) consolidated

(Quartz) sand

PART 1

# BASICS

## ENVIRONMENTAL CONDITIONS & STATE OF CONSERVATION

1

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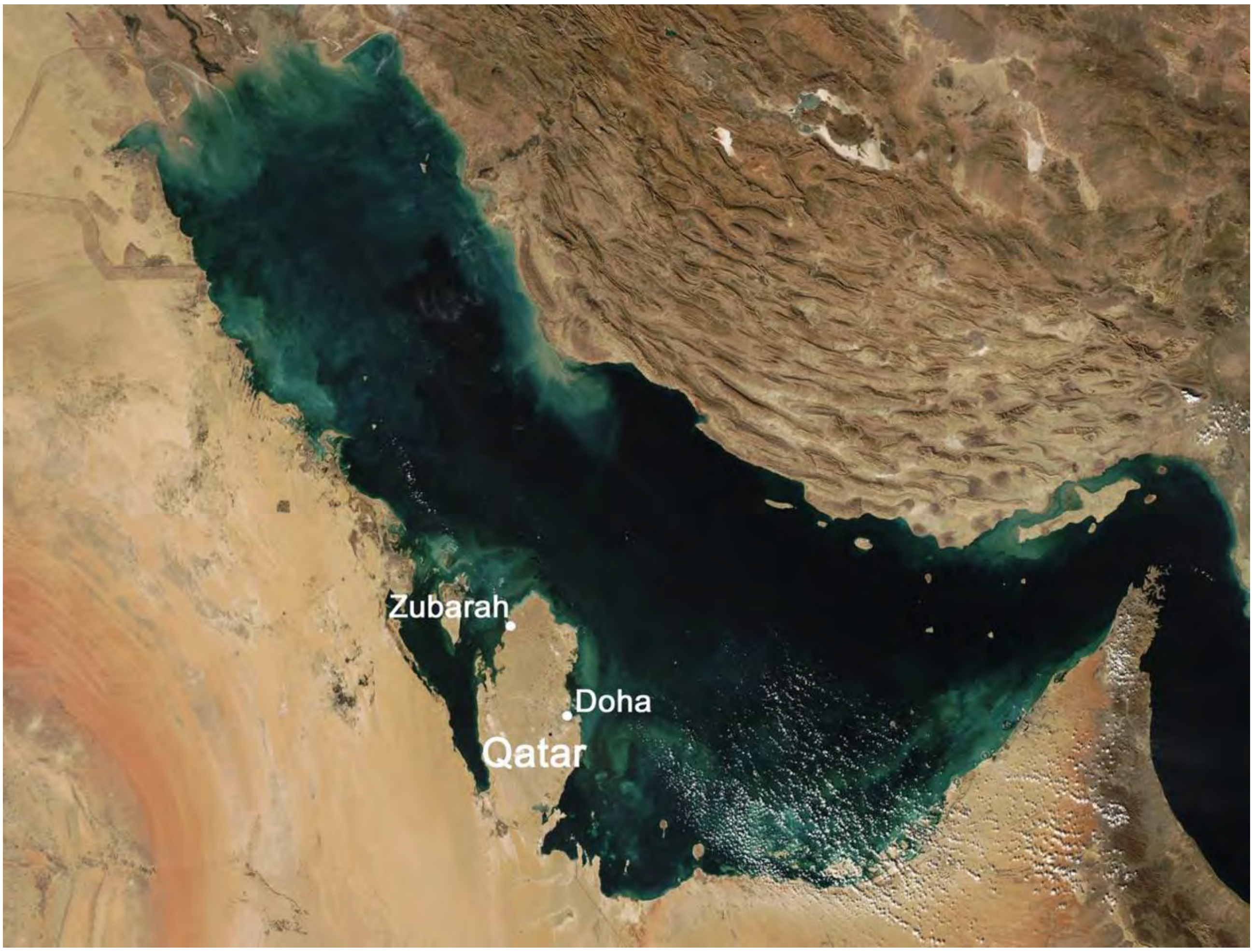
# Introduction to Part 1

Part One of the Conservation Handbook compiles basic information on Al Zubarah Archaeological Site: its archaeology, environmental conditions, state of conservation, deterioration forms, and building materials.

The basic research upon which the conservation strategies and concepts are based are presented here. There is a brief introduction for each area of excavation and the main features of the site. The results of the analyses of climate data collected at Al Zubarah are presented, as well as some thoughts on salts in building materials. The illustrated glossaries are a work in progress. We hope to develop this further and to develop a tool to encompass building terms, building types, and building technologies.

Only through our knowledge of the basics can we formulate a conservation strategy that will be implemented in the field.




Location of Al Zubarah in Qatar and the Gulf Region.

# AL ZUBARAH ARCHAEOLOGICAL SITE
## BRIEF INTRODUCTION

Al Zubarah Archaeological site covers an area of approximately 400ha. Situated on Qatar's north-west coast, it includes the town, the harbour, a sea canal, two screening walls, Qal'at Murair and Al Zubarah fort, which was built in 1938.

The QIAH Project has launched archaeological investigations in five new major areas inside the town, carrying out a survey and excavations at Qal'at Murair, and an intense conservation program to preserve the exposed architectural remains. Excavations have revealed the well-preserved remains of courtyard houses, a souq, parts of a large, palatial compound and segments of the stone build town wall. The so-called *excavation points* (so far ZUEP01 to ZUEP12) covering some *Living quarters* with *courtyard houses* (ZUEP01), the *suq* and harbour area (ZUEP02), some *brush huts* so-called *Barasti* or *Arish*[3] (ZUEP03), the *palatial compound* (ZUEP04), an *midden area extra muros* (EP05), and a walkway with other building structures along the town wall (tower 8/ ZUEP10).

Ceramics and coins found here attest to Al Zubarah's far-reaching trade and economic links in the late 18th century, with artefacts from eastern Asia, Africa, Europe, and the entire Gulf region. Diving weights, Anchors, a pearl merchant's box and other material culture illustrate the close connections between daily life in the settlement, sea trading and the pearl "industry". These close associations between the inhabitants and maritime trade and commerce is further shown by the drawing of a *dhow*, found incised into the wall plaster in a room of a courtyard building (ZUEP01).

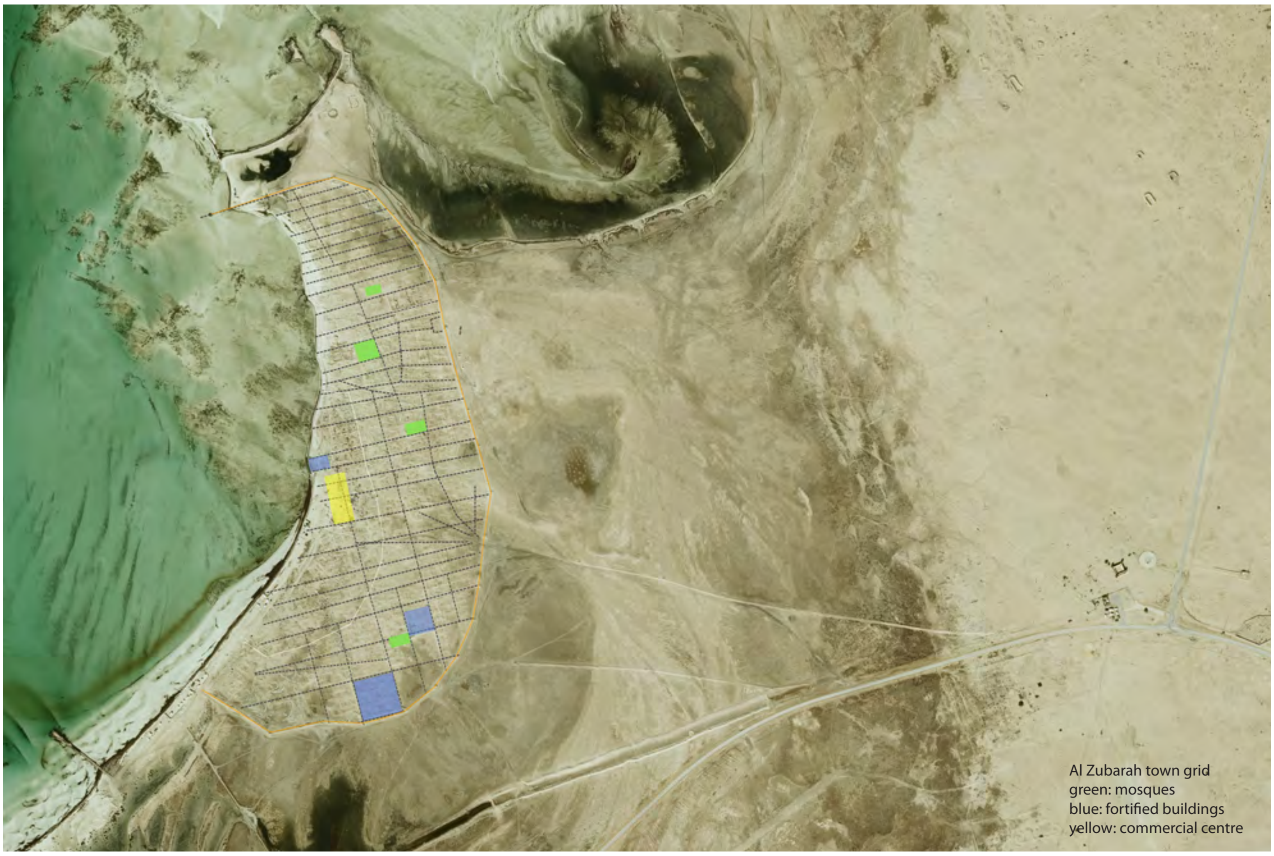
Al Zubarah is an outstanding example of an 18th-19th century pearl fishing and trading town. It is preserved in its entire urban layout with a clearly defined, pre-planned qibla-oriented town grid. Al Zubarah is the only place in the Gulf which still shows the complete layout and fabric of a settlement dating to this crucial and formative period in the region's history.

In the town, at least four mosques have been discovered, as have four "fortified" structures. The largest of these is seen as a palatial compound. The commercial complex of the town including, a suq area, is situated next to the harbour zone of Al Zubarah and shows storage, warehouses, shops and production areas as well as a *Khan*-like building. South of this, near the sea line, remains of *Barasti* or *Arish* palm leaf huts, traditionally used by newly arrived inhabitants and pearl divers, have also been recorded.

Al Zubarah is the only known town in Qatar with a town wall. The 18th century town wall is around 2.5 km long and it has 23 towers. When the town shrunk after the 1811 bombardment a second town wall was erected encircling a much smaller area of 10ha.

It is striking that the buildings at Al Zubarah are predominantly stone built houses, requiring enormous efforts, economically, and on human resources. In other settlements in the Emirates the main components of the towns were primarily palm leaf architecture and only a minority of the buildings were made of stone.

3 Piesik 2012

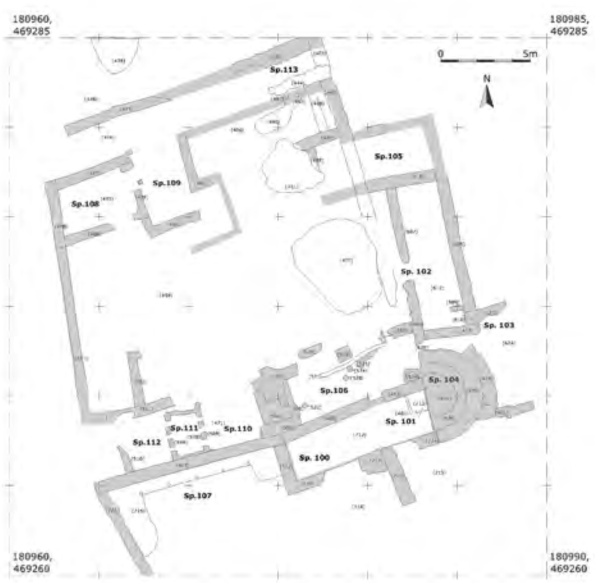



There was, however, one very important resource they were missing: water. The fortified settlement of Qal'at Murair was built to protect and control the nearest wells and water recourse for Al Zubarah. It was linked with the town through a canal and two so-called screening walls, which might be part of a water supply system, overlaying partly the earlier canal. The canal seems to have served as a direct transport link to supply the ships in the harbour with water.


Building materials were mostly sourced locally. Beach rock and conglomerate stone were cut from the ground. Limestone (Dolomite) and Aleolite material was brought in from the plateau between Qal'at Murair and Freiha. Anhydrite as well as gypsum was extracted from the sabkah or nearby outcrops along the former shoreline. Timber had to be imported. It is unclear so far how intense the hinterland was used for agricultural activities (e.g. date palms). For some of the streets, several layers of plaster floors have been discovered and suggest a regular maintenance of the street surfaces.


On the following pages each excavation area will be presented with overview images or plans. Some of the characteristic features appear in detail.

# ZUEP01 - Courtyard houses




**Excavation point 01 (ZUEP01)***: Living quarter with courtyard houses*. In one of the houses a *dhow* was depicted in the wall plaster. This feature was documented carefully in different techniques. It was photographed, drawn, copied with a silicon moulding, scanned with a high-resolution scanner and with photogrammetric techniques. The courtyard houses show bended entrances, reception rooms (*majlis*), kitchen areas and an arcaded *Ivan*.

# ZUEP02 - Commercial Centre (Souq)



**Excavation point 02 (ZUEP02)**: *The Commercial complex* of Al Zubarah is situated next to the harbour zone and includes warehouses, storage, and shops. The warehouse incorporates some date presses (*madbasah*) and a courtyard. The warehouse has a straight entrance to allow direct access to the central courtyard. The room cells of the suq are built in two rows and extend from the earlier excavations (QMA1) to the recently exposed areas (ZUEP02).

# ZUEP04 - Palace

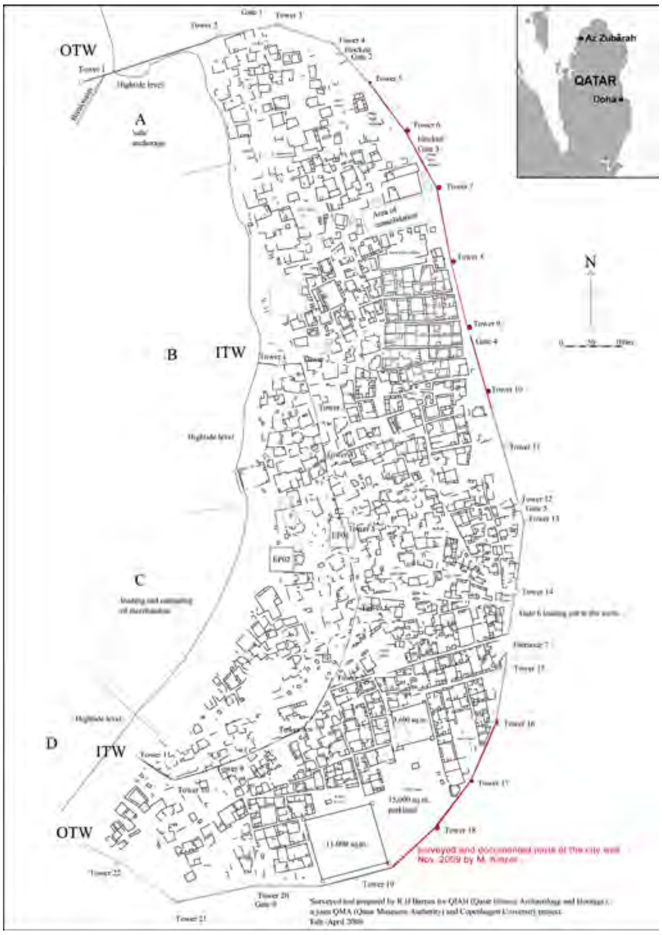
Excavation of the Palace started in early 2010 and has so far exposed one of the nine main courtyards. Decorated plaster and elaborate room arrangements were discovered. The walls are predominantly built from beach rock rendered with an anhydrite-based plaster.

# Town wall and Towers

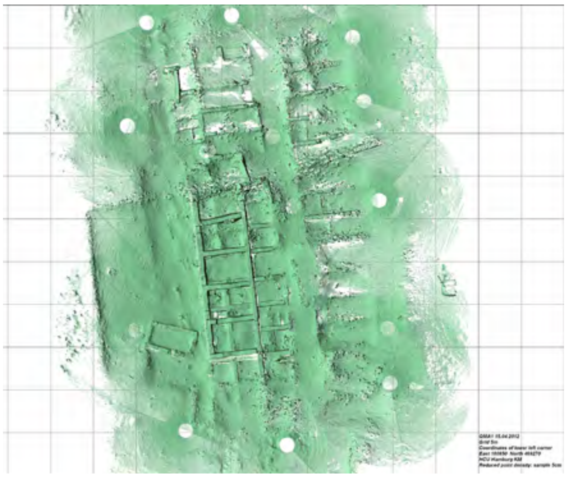

1. Tower 8 and ZUEP10 (2012 before the consolidation).
2. Tower 7, collapsed outer wall face (2010).
3. Town wall at ZUEP04 (2012 after stabilisation).
4. Tower 18, seen from NE (2009).
5. Tower 18, Interior rebuilt in 1980s (2009).

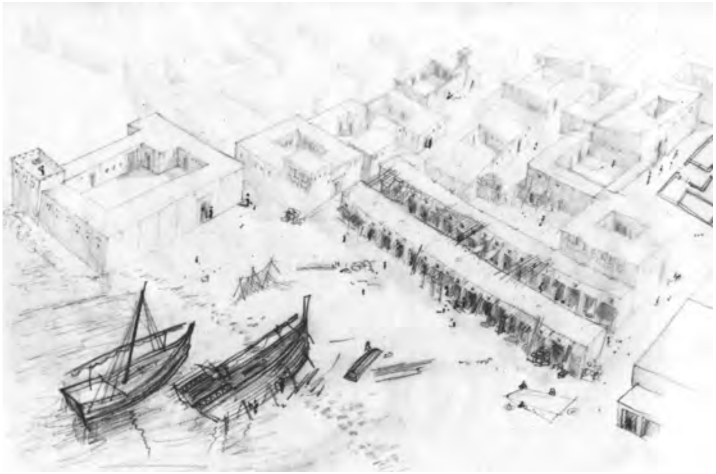




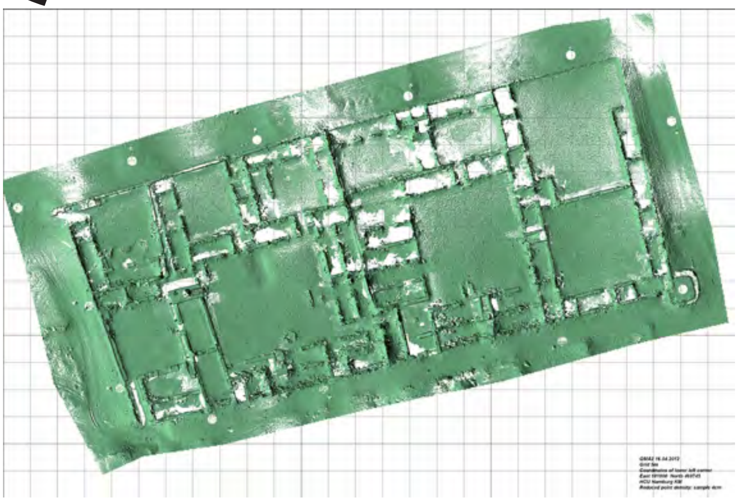


## **QMA 1** - Commercial Centre "Suq"

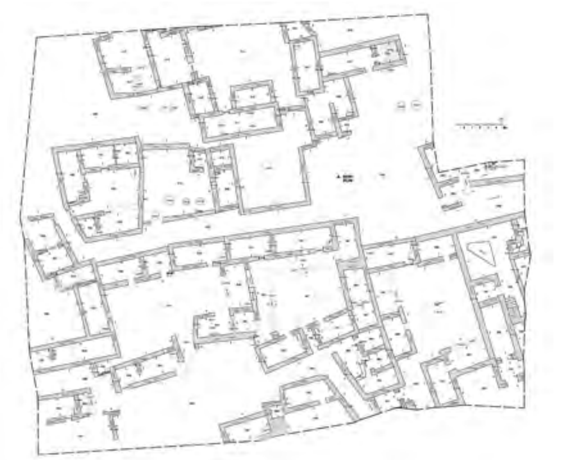




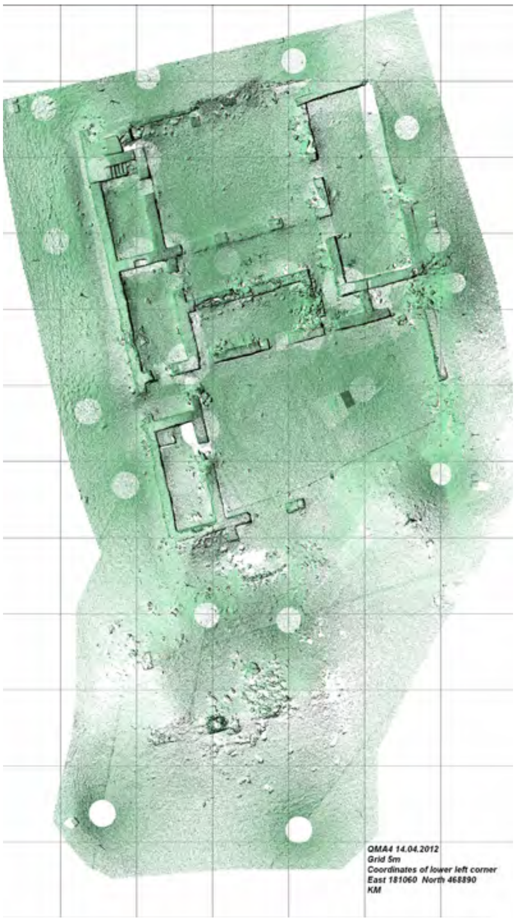
## **QMA 2 -** "North house"



# **QMA 3** - “Industrial Area”



# **QMA 4** - Fortified Compound




# GENERAL ON-SITE CONDITIONS
## A SHORT SUMMARY

Al Zubarah's status as a historic site and an authentic representation of past cultural traditions is threatened by harsh environmental conditions. Erosion caused by the sea, salt efflorescence and crystallisation, wind, drastic change of temperature during the day and human activities are the main issues affecting the conservation of Al Zubarah.

High evaporation rates and the proximity of the sea result in a very high rate of air salinity. This is coupled with very high average of daily and annual temperature ranges, which can reach up to 55°Celsius during the summer months. Sampling and subsequent analysis of exposed mortar and gypsum building materials from Al Zubarah indicate very high salinity concentrations in both mortar and gypsum, which can reach >30% in the sand and soils on-site as well as approximately 15% in the wall structures. This high salinity content causes chemical reactions between the plaster and mortar, resulting in the disintegration of the structural integrity of walls.

Furthermore, strong winds from the north/northwest have undermined the foundations, resulting in structural collapse, while the erosion of wall gypsum plaster has caused the core building materials to fall apart. Heavy winter rains and a constant change of humidity during the day (averaging around 20% to 50%) also puts a lot of pressure on the building materials.

These natural environmental agents are difficult to mitigate against. In general, there is also a huge impact from wash-out and blow-out processes on the walls, e.g. the very soft beach-stones (type "Ag") are in a very poor state. Erosion has left voids within the wall structures, as well as the disintegration of entire wall segments.

Most of the building materials were not chosen to perform under these environmental conditions: e.g. the soft beachrock was used inside walls and was protected by plaster. The same is true for the interior plasters.

Although the architecture at Al Zubarah can be seen as "stone architecture" it shares several characteristics with earthen architecture. The decay process of the so-called beachrock has more in common with the erosion of mud bricks than with the deterioration of building stones.

# GENERAL ON-SITE CONDITIONS
## A SHORT SUMMARY

TEMPERATURES BETWEEN 5°C – 55°C

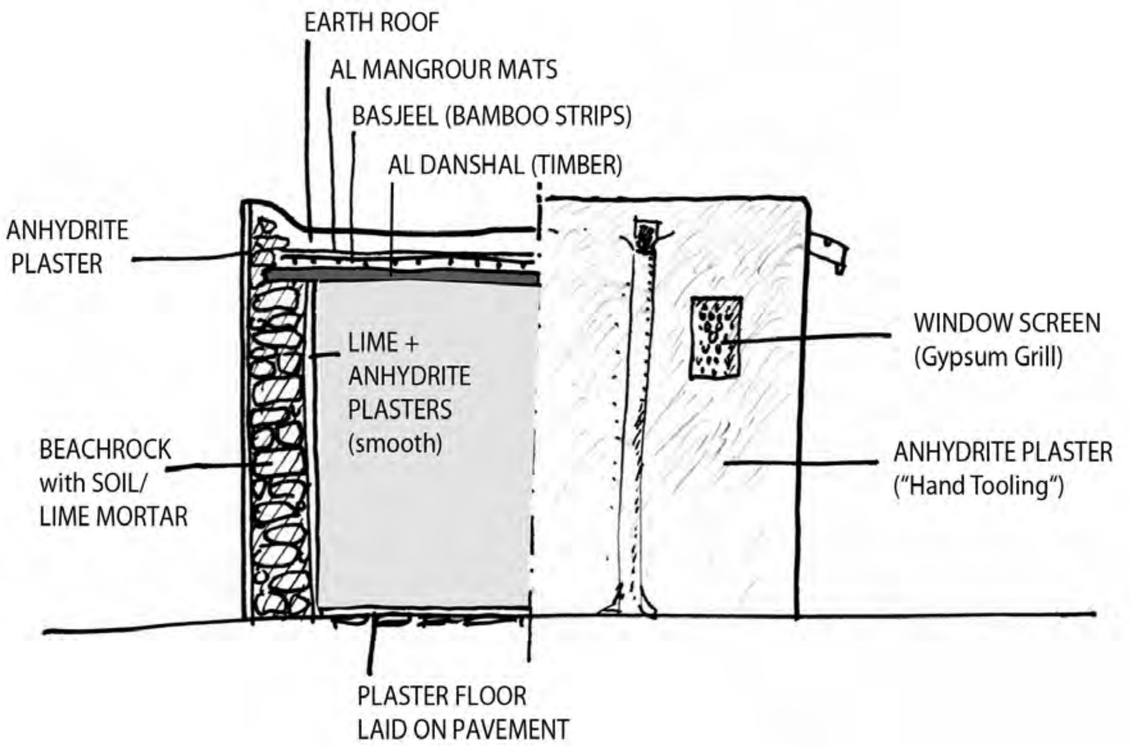
HEAVY WINTER RAINS

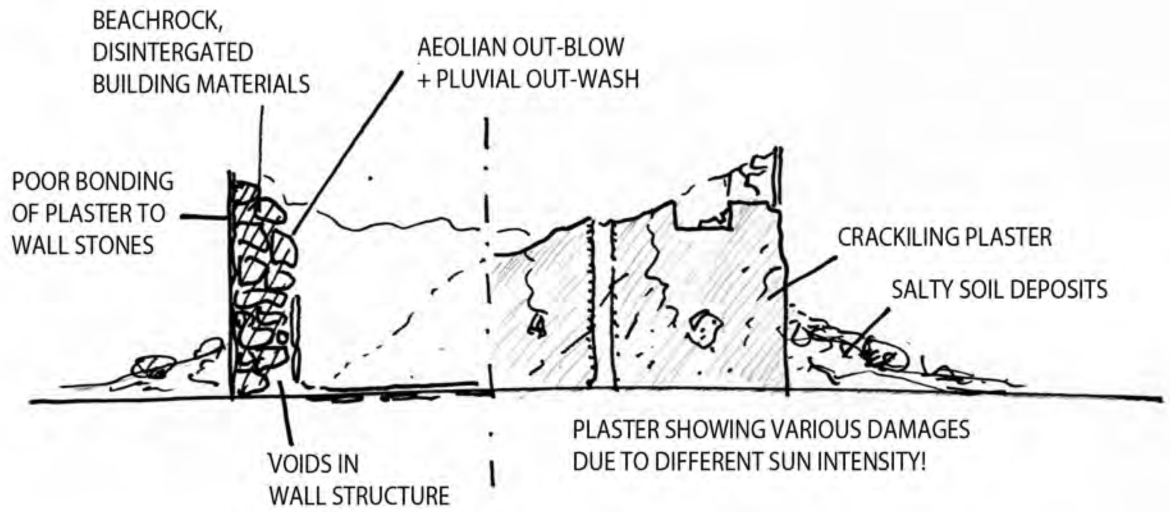
STRONG NORTH-/NORTHWEST WINDS

UP TO 30% SALT IN SOIL/SAND

UP TO 16% SALT IN WALL STRUCTURES

20% – 50% CHANGES IN HUMIDITY DURING DAY



# ENVIRONMENTAL CONDITIONS
## CLIMATE DATA (MONITORING)




Fig.1, 2, 3: Temperature/humidity data loggers at QMA2 in Al Zubarah town (D1, D2) and HAB54506 at Al Zubarah Fort (indoor).

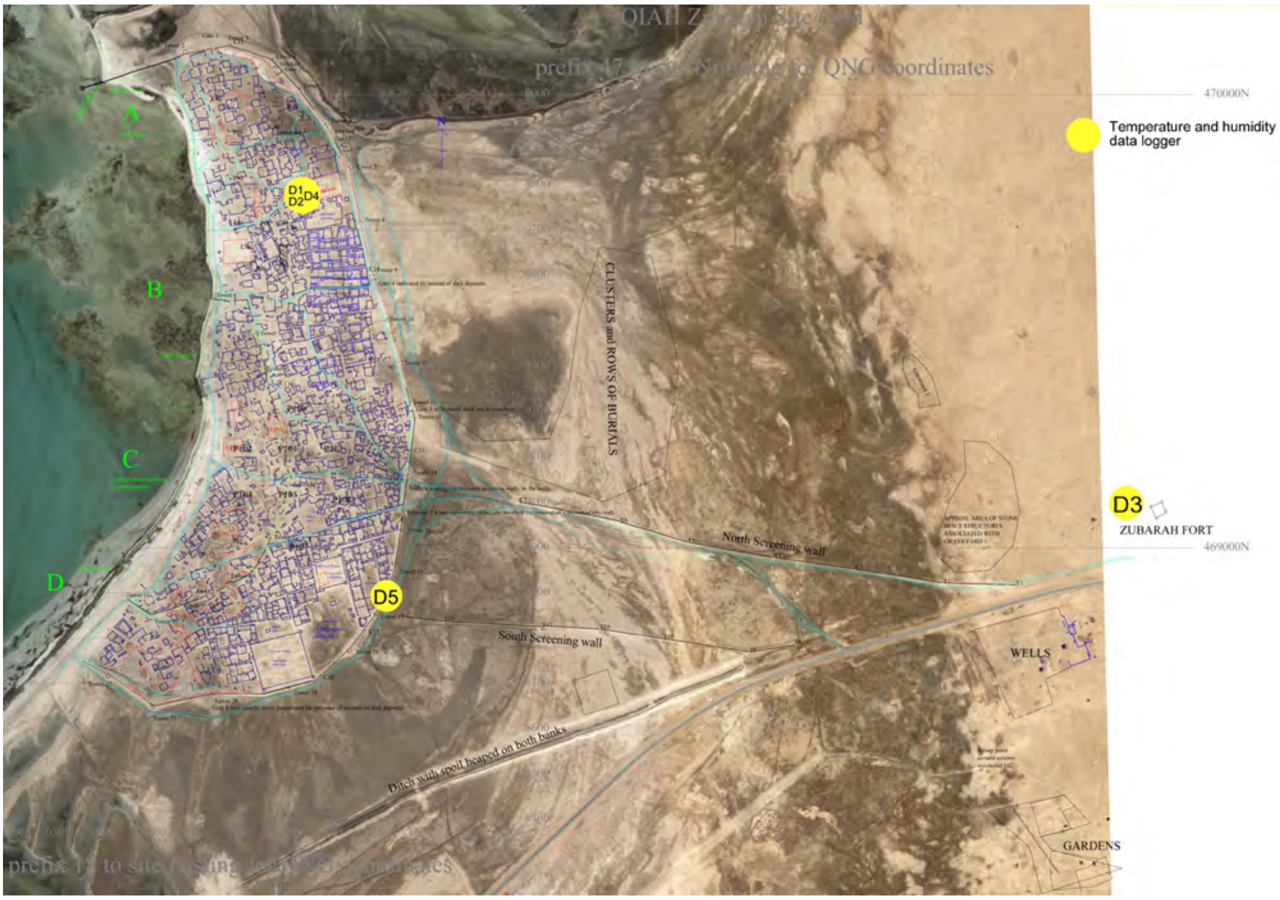



Fig. 4: Positions of the temperature/humidity data loggers in Al Zubarah town (D1, D2, D4, D5, HAB54579), at the research station (D3), and in a building of the fort (HAB54506)

## CLIMATE OF QATAR
## IMPACT ON THE WEATHERING OF BUILDING MATERIALS

The climate of Qatar as described by the Encyclopaedia Britannica as follows:

*"a notoriously unpleasant climate. Temperatures are high, though winters may be quite cool at the north-western extremities. Summer (June to September) is very hot with low rainfall. Daily maximum temperatures can reach easily 40°C or more. Winter is cooler with occasional rainfall. Spring and autumn are warm, mostly dry and pleasant, with maximum temperatures between 25°C and 35°C and cooler night temperatures between 15 and 22°C. The sparse rainfall occurs mainly as sharp downpours between November and April and is higher in the northeast. Humidity is high. The little cloud cover is more prevalent in winter than in summer. Thunderstorms and fog are rare, but dust storms and haze occur frequently in summer. The shamal, a wind that blows predominantly from a north-northwest direction during the summer, is seldom strong and rarely reaches gale force. Squalls and waterspouts are common in autumn, when winds sometimes reach speeds of 95 miles (150 km) per hour within as short a time as five minutes. Intense heating of the land adjacent to the coasts leads to gentle offshore winds in the mornings and strong onshore winds in the afternoons and evenings."*

Temperature and humidity data for Doha on the East coast of the peninsular is summarised in Fig. 5.

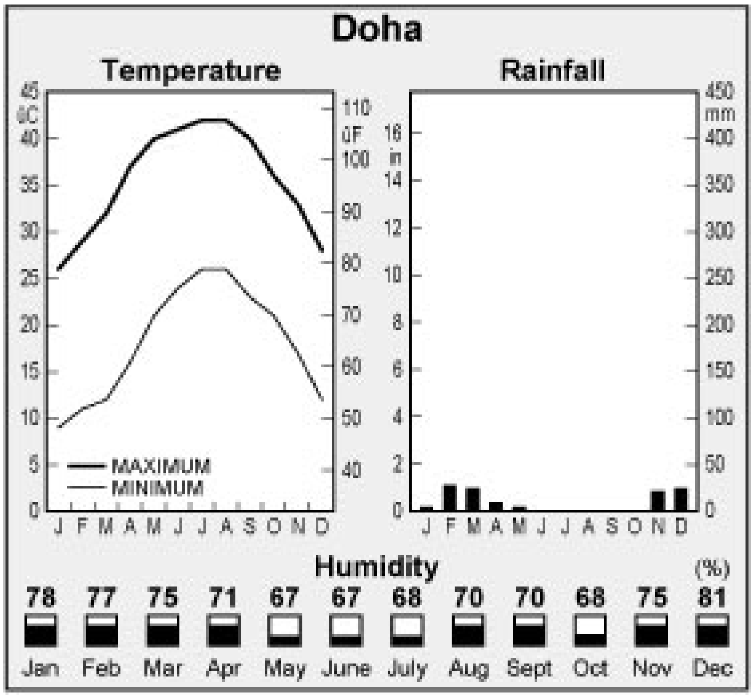



Fig.5: Temperature and humidity data for Doha, Qatar

Temperature, humidity and wind all contribute to the weathering of building materials. A bigger range in temperature during the day will lead to an increase in thermal dilatation and, eventually, greater potential damage to the building through the development of cracks. Building materials with distinctly different thermal expansion coefficients (> 10-5/K ) are particularly prone to damage. The heating of wall surfaces depends on the duration of direct sun exposure and the absolute temperature high. Therefore, the weathering of building materials through thermal dilatation primarily takes place during summer.

Humidity is a problem during the winter months, when it exceeds 74.6%, the value of deliquescence and the crystallisation of sodium chloride (at 20°C). The repeated crystallisation of sodium chloride in the pores of building materials eventually leads to a weakening of the fabric and, ultimately, to crumbling. The effect of repeated deliquescence and crystallisation of sodium chloride can be seen everywhere in Al Zubarah, where the debris of beach rock (especially type AG) accumulates up at the bottom of walls. Strong winds and sandstorms also contribute to the weathering of building materials by the transport of sand grains which act abrasively on the surfaces.

In order to gather detailed information on the climate of Al Zubarah, seven temperature/humidity data loggers were distributed over the town area, at the research station and inside a building of the fort (Fig.1 to 3). The localities are marked in Figure 4. The data loggers were distributed with respect to different geographical positions (close to the sea, more inland) and exposure situations (free exposure, protected position in a niche, wall crevice or under a stone, inside a building). One of the data loggers (D2) failed to record data over a longer period of time (more than several days). All data loggers are listed in Table 1 with their number, geographical position, exposure situation, and recording time.

Figure 6 shows that the data collected so far is fragmentary. However, the incomplete bell-shaped average temperature curve for 2011 is in agreement with the complete minimum and maximum temperature curves for Doha in Figure 5. Figure 7 shows the corresponding humidity curves.

| Number | Position | Exposure | Recording time |
|---|---|---|---|
| D1 | QMA 2 | free (at top of a pole) | 22.03. - 30.05.2012 |
| D2 | QMA 2 | free (at bottom of a pole) | 22.03. - 23.03.2012 |
| D3 | Research Station | free (west gable of workshop) | 22.03. - 30.05.2012 |
| D4 | QMA 2 | protected (in a wall crevice) | 22.03. - 30.05.2012 |
| D5 | EP 04, tower 8 | protected (under a stone) | 22.03. - 30.05.2012 |
| HAB0054679 | QMA 2 | protected | 16.01. - 16.02.2011 |
| HAB0054506 | Al Zubarah Fort | protected (inside a room) | 21.03. - 20.09.2011 |

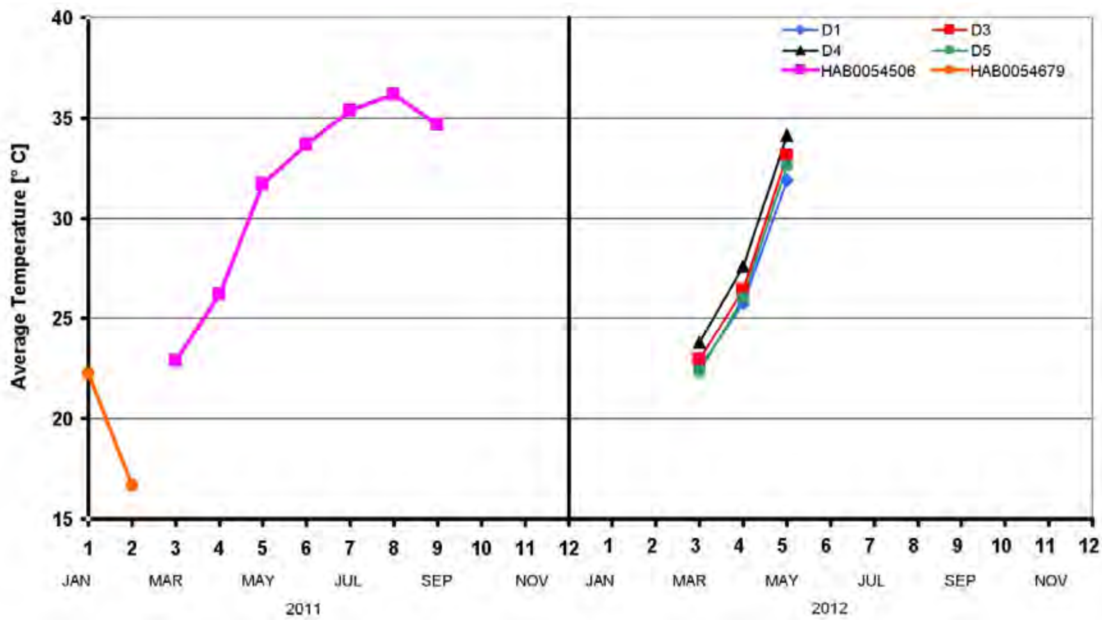



Fig.6: Average temperature data at different locations at Al Zubarah

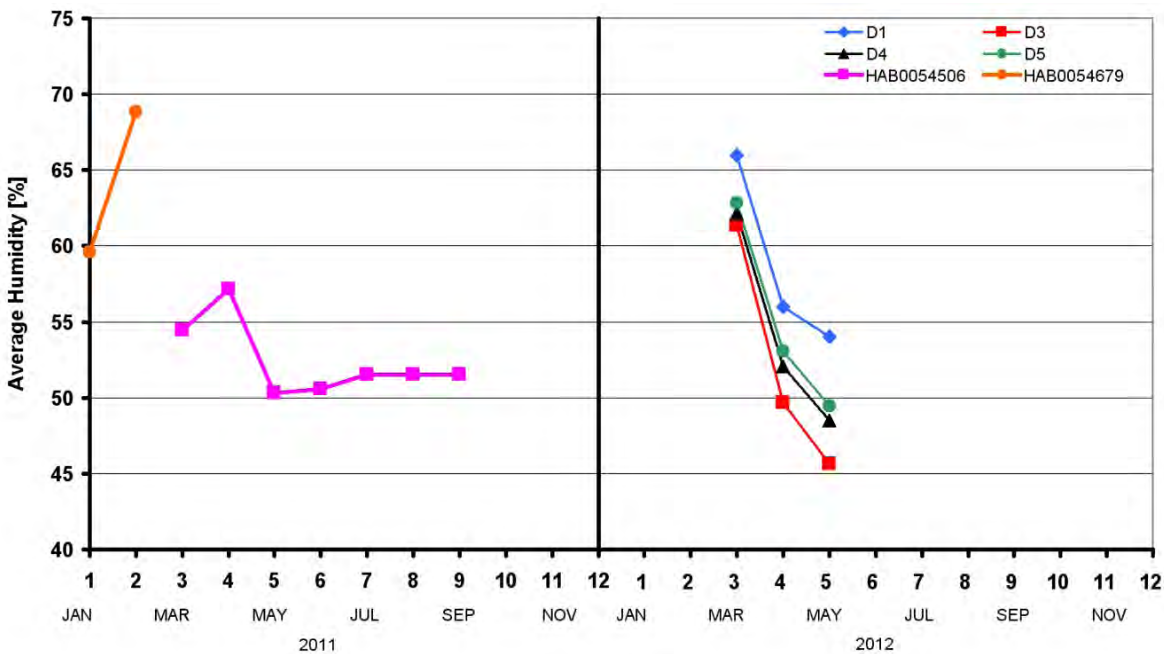



Fig.7: Average humidity at different locations at Al Zubarah.

A comparison of the curves shown in Figures 6 and 7 and Figures 8 and 9 shows that temperature and humidity are inversely correlated: humidity is low when the temperature is high and vice versa.

Figure 8 shows that the daily temperature maximum occurs between 12 and 13 hours, while the lowest temperatures occur in the time interval 24 to 3 hours. The temperature peaks are lower and broader for data loggers kept in protected positions (e. g. D4, D5). The maximum inland temperature (D3) is a little bit higher than the maximum temperature close to the sea (D1, D2). The recorded temperature data – although it's not yet complete – enables a reasonable assessment of the daily and annual air temperature course. What is missing is surface temperature data for building stones and plasters to appraise the effect that thermal dilatation may have on them.

In Figure 9, the green horizontal line marks the deliquescence of sodium chloride. At 20°C and 74.6% relative humidity solid sodium chloride liquefies to a saturated brine. According to the humidity curve shown in Figure 9 this happens during the night hours when the temperature is close to the minimum. In the morning when the temperature rises and the humidity decreases and falls below the critical value of 74.6% sodium chloride crystallises again from the saturated brine. Deliquescence and crystallisation of sodium chloride takes place preferably in the colder winter period, as is shown in Figures 10 and 11.

It can be said that salt crystallisation is a weathering factor which is most active in the winter period, while thermal dilatation occurs predominantly during the summer. Our information about the impact of climate on the weathering of building materials at Al Zubarah will be improved with more data from well-positioned data loggers over the area. The evaluated data of the seven data loggers is presented in Tables and Figures in Appendix 8.

Robert Sobott, July 2012

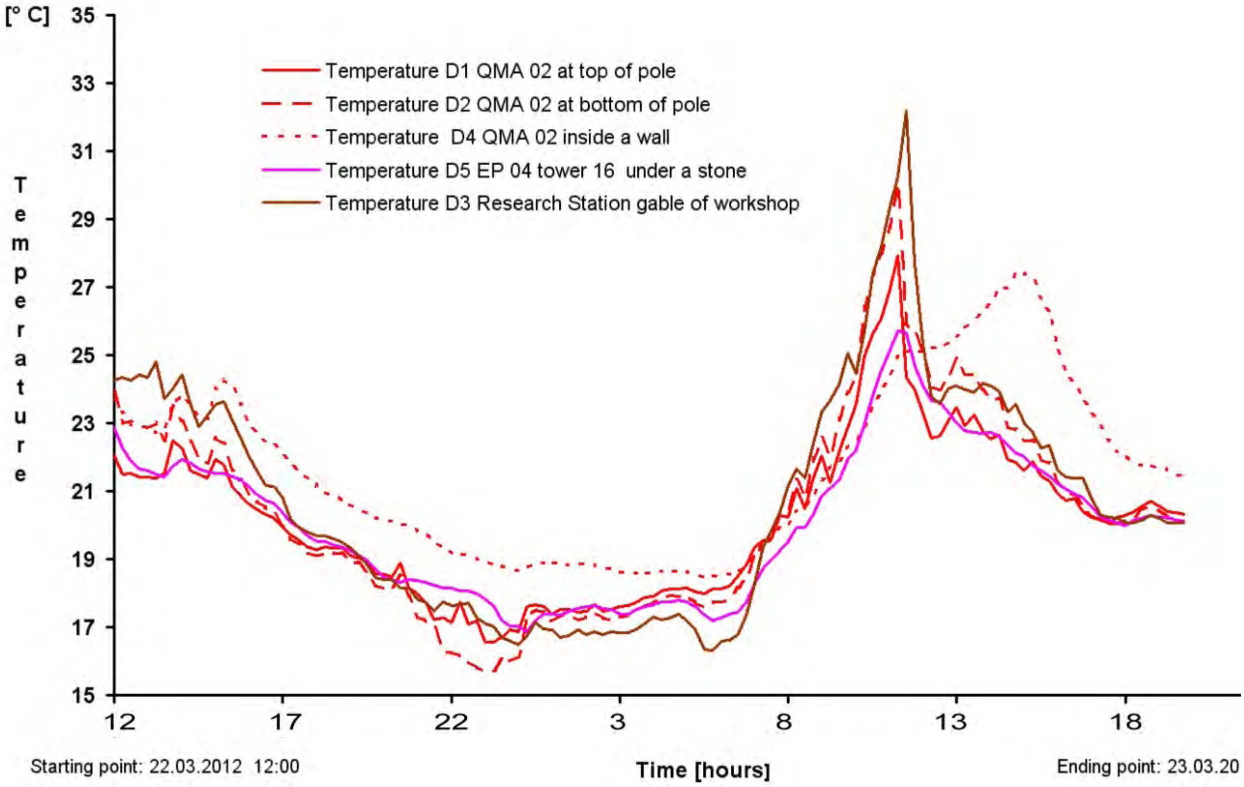



Fig.8: Temperature curves from data-logger D1 - D5 for the time period 22.03. - 23.03.2012

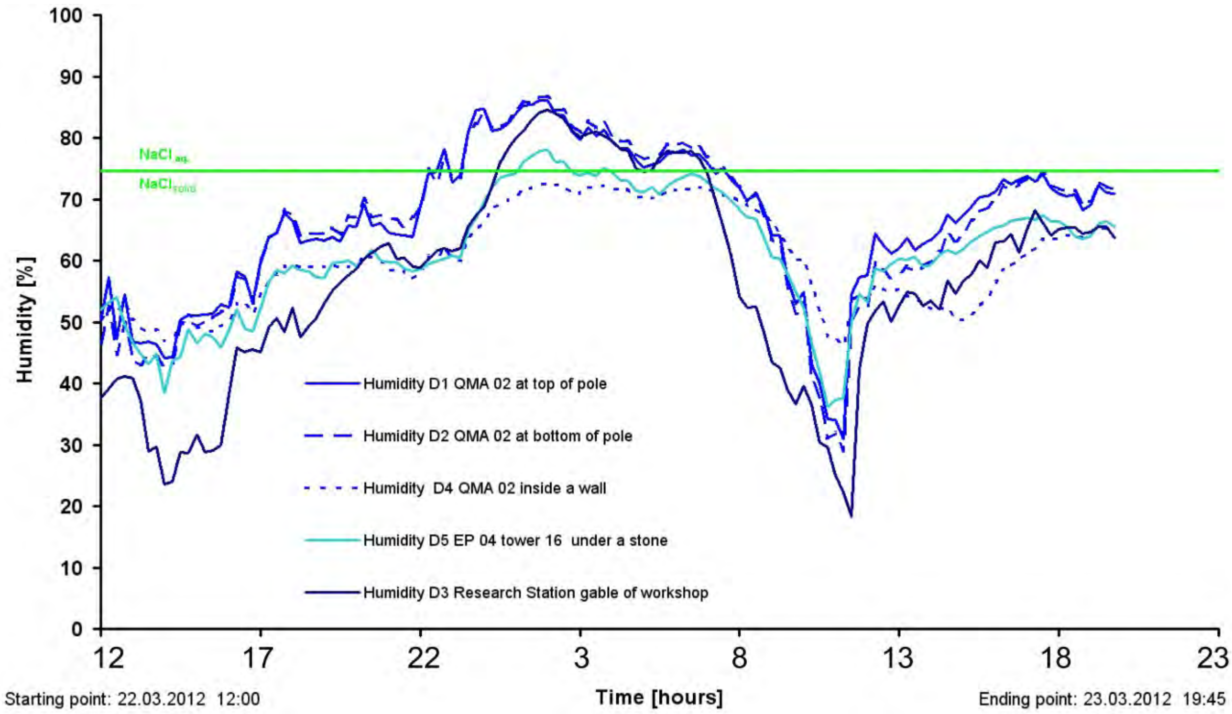



Fig.9: Humidity curves from data-logger D1 - D5 for the time period 22.03. - 23.03.2012

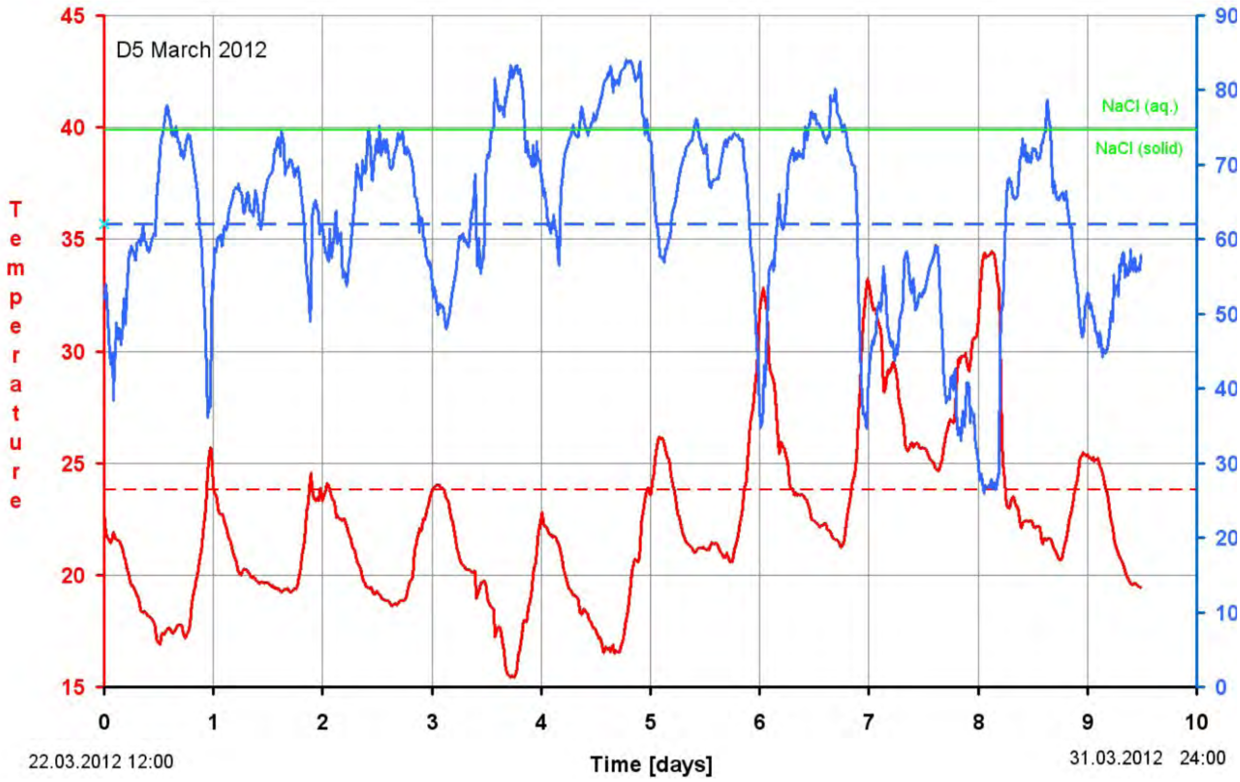



Fig.10: Temperature / Humidity curves from data-logger D5 for March 2012

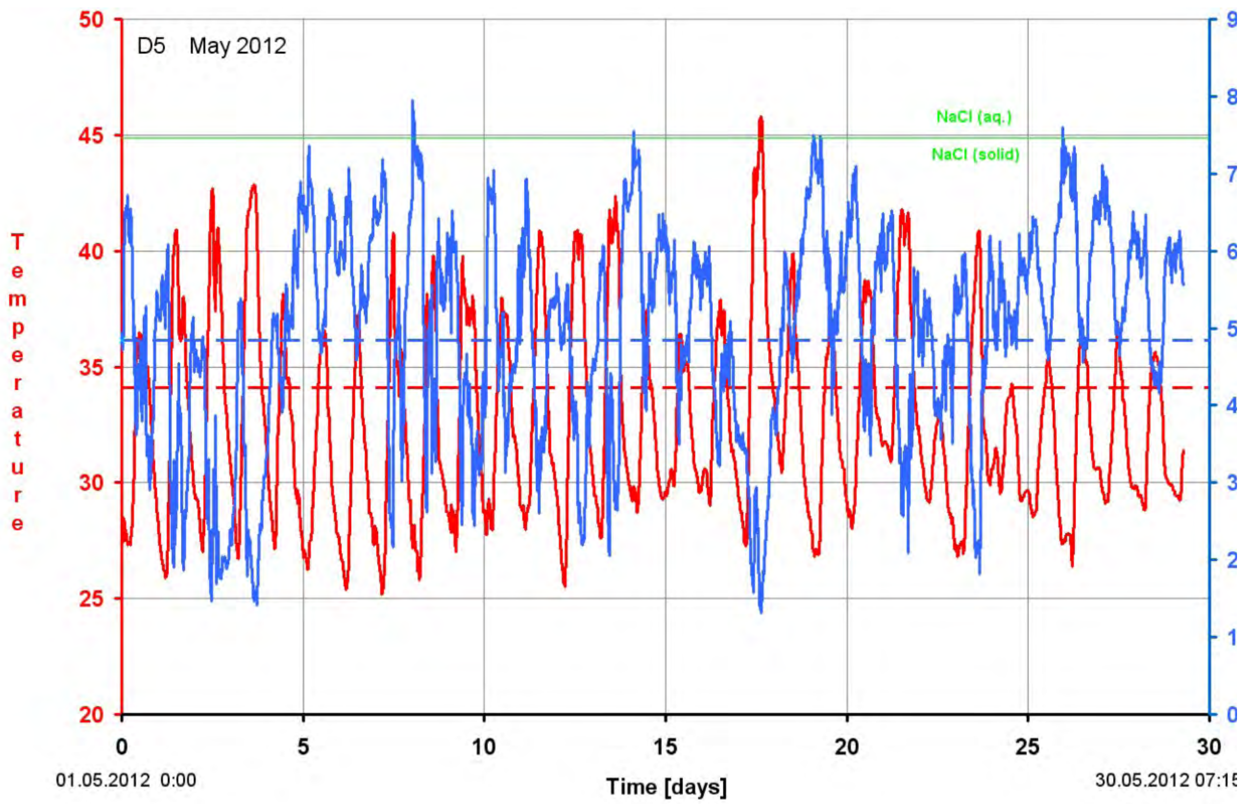



Fig.11: Temperature / Humidity curves from data-logger D5 for May 2012

# WEATHERING PROCESSES UNDER THE ENVIRONMENTAL CONDITIONS AT AL ZUBARAH

The environmental conditions at Al Zubarah are determined by distinct daily changes in relative air humidity, frequent strong winds blowing mainly from northern directions, and the abundance of sodium chloride transported by sea water and wind. These three factors give rise to intensive physical and chemical weathering of building materials. Since they are unchangeable the consequences can only be mitigated by the choice of appropriate building materials and continuous maintenance.

**Physical weathering processes**
Physical weathering at Al Zubarah is mainly caused by wind erosion. Strong winds carrying sand particles act much the same way as industrial sand blasting. Soft and weakly consolidated building stones such as beachrocks are preferably affected and definitely need a protective plaster.

Thermal cracking of individual or composite building materials can be the consequence of two different processes. In the first case it is caused by weakening the bonds between the components of a building material by thermal stresses induced by anisotropic dilatation of the components on a microscopic scale due to repeated rapid and great temperature changes. An example for this process is the cracking of a boulder in the desert where daily air temperature differences up to 50°C are not uncommon.

In the second case, the composite structure of a building unit is disrupted by sheer stresses in the interface of building materials with distinctly different thermal dilatation coefficients. To become effective this process requires large temperature differences. A worst case example would be a thick, insulating render with a high thermal dilatation coefficient on a stone wall surface with moderate to low thermal expansion. Thermal cracking is supposed to play a subordinate role in the physical weathering of building materials at Al Zubarah. Although absolute temperatures can be very high, daily temperature changes are gradual and the difference in the morning and early afternoon temperature rarely exceeds 20°C.

No consideration must be given to the destructive effects of ice crystallisation in the pore space of fully water-saturated building materials.

**1. Physico-chemical weathering**
Physico-chemical weathering comprises the chemical reactions between water and water-soluble salts in the pore space of building materials and is effected by the pressure exerted by hydrating and crystallising salts on the pore walls. Therefore, it requires water and water-soluble salts which are both present at Al Zubarah in unlimited quantities.

Water sources are groundwater, condensed air humidity, and sea spray. Salts, mainly sodium chloride (halite), and to a smaller degree alkali earth sulphates (gypsum, epsomite, etc.), are derived from the sea water. The components of salts, positively charged cations and negatively charged simple or complex anions, are bonded by electrostatic forces in a crystal structure.

Salts are water-soluble when the hydration energy derived from the interaction of strongly polarised water molecules with the ions is greater than the bond energy between the ions. The interaction with water makes salts harmful to building materials because without water there would be no transport to, into, and in the building materials and no destructive reactions. Therefore the occurrence of salts is also always an indication of moisture in the masonry.

The combination of sulphate, carbonate, nitrate, chloride, phosphate, oxalate, and acetate anions with sodium, potassium, magnesium, calcium, and ammonium cations produced some fifty different salts which were identified in building materials. Apart from simple salts, which consist of one cation and anion there are double and triple salts, frequently with several molecules of crystal water. Very remarkable species are humberstonite, $K_3Na_7Mg_2(SO_4)_6(NO_3)_2*6H_2O$. and thecotrichite, $Ca_2(CH_3COO)_3Cl(NO_3)_2*7H_2O$. However, if only the ubiquitous salts are considered, only 11 species remain of which gypsum and thenardite are by far the most frequent. Together with halite these two salts play an important role in the physico-chemical weathering processes taking place at Al Zubarah.

Salt contents in building materials are recognisable either as white efflorescences or dark patches on the surface of building stones, renders, and mortars. The crystallisation of salts takes place when the relative humidity of the air is lower than the deliquescence relative humidity. Sodium chloride (deliquescence relative humidity 75.4%), for example, occurs as crystallised rock salt or halite at 20°C and 60% relative humidity, while under the same conditions solid nitrocalcite, $Ca(NO_3)_2*4H_2O$), (deliquescence relative humidity 53,6 %) takes up water from the air and dissolves. Salts with a very strong affinity to water practically never crystallise under ambient conditions and impart affected masonry a conspicuous dark colour.

**2. Origin of salts**

The formation of salts in building materials requires the presence of the cations and anions mentioned above. As a matter of fact, there are many possibilities as to how salts get into the stones and mortars of masonry. First of all, the building materials, stones and mortars, may contribute to the formation of salts. By the gradual decay of chemically less stable rock components, such as feldspars sodium and potassium, ions are set free, and the weathering of dolomitic rocks produces magnesium ions. The reaction of slaked lime (portlandite) and calcium silicate phases, the principal constituents of lime mortar and Portland cement, with water yields calcium ions which form low soluble compounds such as calcite and calcium silicate hydrates. Depending on the amount of $CO_2$ dissolved in water, calcite is partly dissolved again and therefore limestones and mortars are potential sources of calcium. If the raw material for burning lime contained appreciable amounts of dolomite then the mortar will contribute magnesium for the formation of magnesium salts.

The use of gypsum as binder introduced calcium and sulphate to the masonry, which may be mobilised by moisture. Some Portland cements contain distinct amounts of alkalis which are soluble and mobile in alkaline pore waters. Dry and wet deposition of the air pollutants $SO_2$ and $NO_X$ on building materials, in combination with catalytic oxidation sulphate and nitrate ions are formed. In the masonry they encounter a mix of cations and controlled by solubility combine with them to a variety of salts. Crystallisation of salts preferably takes place on limestone surfaces sheltered from the rain and leads to the growth of more or less thick and black gypsum crusts. However, these salt-forming processes are restricted to industrialised areas where energy is provided by fossil fuel power plants and densely populated areas with a lot of car traffic. Neither of these applies to the Al Zubarah region.

An important source of nitrates in masonry is the nitrification of organic matter by the nitrifying bacteria nitrosomonas and nitrobacter. High nitrate concentrations are quite common in the walls of horse and pig stables and, as a matter of fact, niter crusts were once a valued commodity for the production of gunpowder. Nitrates may occur in Al Zubarah where organic materials were stored and succumbed to bacterial degradation.

The high amount of sodium chloride in the building materials is derived from the sea water and like the other salts distributed in the masonry by capillary transport. The hygroscopic nitrates and chlorides are very mobile and migrate considerable distances from the spot of emplacement or formation.

Fig. 1 a Crystallisation of sodium chloride (halite) on *sabkha* at Zubarah.

Fig. 1 b Crystallisation of sodium chloride (halite) on wall render at Al Zubarah.

**3. Analytical methods for determining salt concentrations**

There are a number of qualitative and quantitative methods for determining salt concentrations in building materials. For example, by licking a white crust on a building stone it is possible to distinguish magnesium sulphate hydrates (epsomite, hexahydrate) from sodium chloride by the characteristic bitter taste. However, the value of sensorial tests is very limited and reliable qualitative and quantitative analyses require greater effort with respect to methods and equipment.

**3.1 Electrical conductivity measurements**

Water-soluble salts can be extracted from building materials with distilled water. Positively charged cations ($Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$) and negatively charged anions ($Cl^-$, $NO^{3-}$, $HCO^{3-}$, $SO_4^{2-}$) are formed and conduct an electrical current. For diluted solutions there is a linear correlation between the electrical conductivity of the solution and the concentration of dissolved salts. The more salt the solution contains, the higher will be the electrical conductivity. A saturated and neutral calcium sulphate solution (~ 2 g $CaSO_4$ / 1000 $cm^3$ at 20 °C) exhibits an electrical conductivity of about 2.3mS/cm. The electrical conductivity is related to the sum of dissolved ionic species but does not inform about the kind of dissolved salts. The measurement of electrical conductivity is well suited for the rapid and uncomplicated determination of total dissolved solids and, in combination with Merckoquant® test strips, even semi-quantative analyses of sulphate, nitrate, chloride, calcium and potassium ions are possible.

**3.2 Quantitative chemical analysis (AAS , ICP-OES, , IC)**
The quantitative analysis of cations in the eluate of a building material is done by atomic absorption spectroscopy (AAS) or inductively coupled plasma/optical emission spectometry (ICP-OES) while the anions are analysed by ion chromatography. (IC). Conventionally, the contents of $Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$, $SO_4^{2-}$, $NO^{3-}$, and $Cl^-$ in the eluate are determined and recalculated to solid-related salt concentrations in percent. Ammonium and hydrogencarbonate ions are not included in the routine chemical analysis which is supplemented by the measurement of the electrical conductivity and pH. The determination of pH is especially necessary if the sample is a relatively young mortar which yields an eluate with a pH > 10. In this case an apparent excess of calcium ions which cannot be accounted for by sulphate, nitrate, and/or chloride contents in the sample is explained by the presence of hydroxl ions derived from the dissociation of portlandite.

The plausibility of the analytical result should be checked by an ion balance and the comparison of the measured and calculated electrical conductivity taking also the pH into consideration. The sum of the concentrations of anions in terms of ion equivalents should equal the total concentration of cations in terms of ion equivalents. If the solubility and deliquescence relative humidity are considered the ion balance allows a forecast of the crystallisation sequence of salts from the solution. The least soluble salts will crystallise first, and the most soluble last. The data from chemical analyses can also be used for a numerical simulation of brine crystallisation at a given temperature and relative humidity conditions (Steiger 2005). The computer program "ECOS" (Environmental Control for Salt Damage) can be applied for this purpose (Price 2000).

**3.3 X-ray diffractometry**
Salts are crystalline solids and can be identified by X-ray diffractometry. Since the wavelengths of X-rays are in the order of magnitude of the interplanar spacings in crystals, reflection and diffraction phenomena occur at the surface of irradiated crystals and produce a compound specific diffraction pattern. Evaluation of the diffractogram with Bragg's equation turns diffraction angles into interplanar spacings (d values) which are listed for some ten thousand inorganic and organic substances. The identification is done by comparison of listed and measured d values. Individual constituents in salt mixtures can be identified if their concentration exceeds 1 mass%. Under favourable conditions, i.e. if the constituents have similar mass absorption coefficients and no preferred orientation of the crystallites in the sample, the peak intensities may be used for estimating approximate quantities.

**4. Interaction of salts with building materials**
The harm caused by salts to building materials is demonstrated by damages to paint coatings on render, which may become visible after several cycles of deliquescence and crystallisation. If the paint coating is barely permeable to the brine, salt does not crystallise on the paint coating but behind it and pushes it away from the render. Analogous to this process the harmful effects of salt crystallisation in the pore space of building stones can be imagined.

If the sum of volumes of crystallised salt and residual solution is greater than the volume of the supersaturated brine, a crystallisation pressure develops inside the pores provided they have been sealed off by crystallised salt. This process is comparable to the crystallisation of ice in a bottle completely filled with water which will burst because the ice has a greater volume than the water. As suggested by thermodynamical considerations and confirmed by experiments with alum, not only the expanding volume but also the growth of crystals in preferred crystallographical directions effects a pressure which is capable of disrupting the fabric of building materials. However, the quantitative contribution of the linear growth crystallisation pressure to the damage of building stones is difficult to assess because theoretical considerations do not completely agree with observations at buildings.

According to theoretical calculations, the crystallisation of halite from a twofold supersaturated solution effects a pressure almost twice as high as the crystallisation of thenardite under the same conditions. However, in cases where salt crystallisation plays a major role in damaging building stones it is mostly linked to sodium and/or magnesium sulphate and not to sodium chloride. The decay of building stones by salt crystallisation has been the subject of a number of dissertations (Hoffmann 1994, Weiss 1992). They confirm the hypothesis that salt crystallises with a pressure build-up from a constantly supplied brine due to the lower chemical potential in capillary pores first and will continue to crystallise in micropores when the pressure in the capillary pores has reached a level at which the chemical potential of the salt crystals in the capillary and micro pores is equal (Fitzner and Snethlage 1983). The magnitude of the resulting pressure depends on the absolute pore sizes and the pore size distribution. This capillary pressure model goes along with the observation that building stones with a maximum of the pore size distribution in the overlap interval of capillary and micro pores are specially prone to damage by salt crystallisation while building stones with a maximum in the macro pore interval are much more resistant.

Next to the crystallisation pressure, the hydration pressure of salts occurring with several molecules of water of hydration contributes greatly to the harmful interaction of building materials with salt.

By the uptake of waters some salts pass from a lower into a higher hydration stage with an increase in molar volume. This effect is especially distinct for sodium sulphate, where the uptake of water leads to the transformation of anhydrous thenardite to mirabilite with ten molecules of water accompanied by an increase of the molar volume by 310%! A second example is magnesium sulphate, which occurs in five different hydration stages: kieserite Mg2SO4*H2O, starkeyite $Mg_2SO_4*4H_2O$, pentahydrite $Mg_2SO_4*5H_2O$, hexahydrite $Mg_2SO_4*6H_2O$, and epsomite $Mg_2SO_4*7H_2O$. The increas-

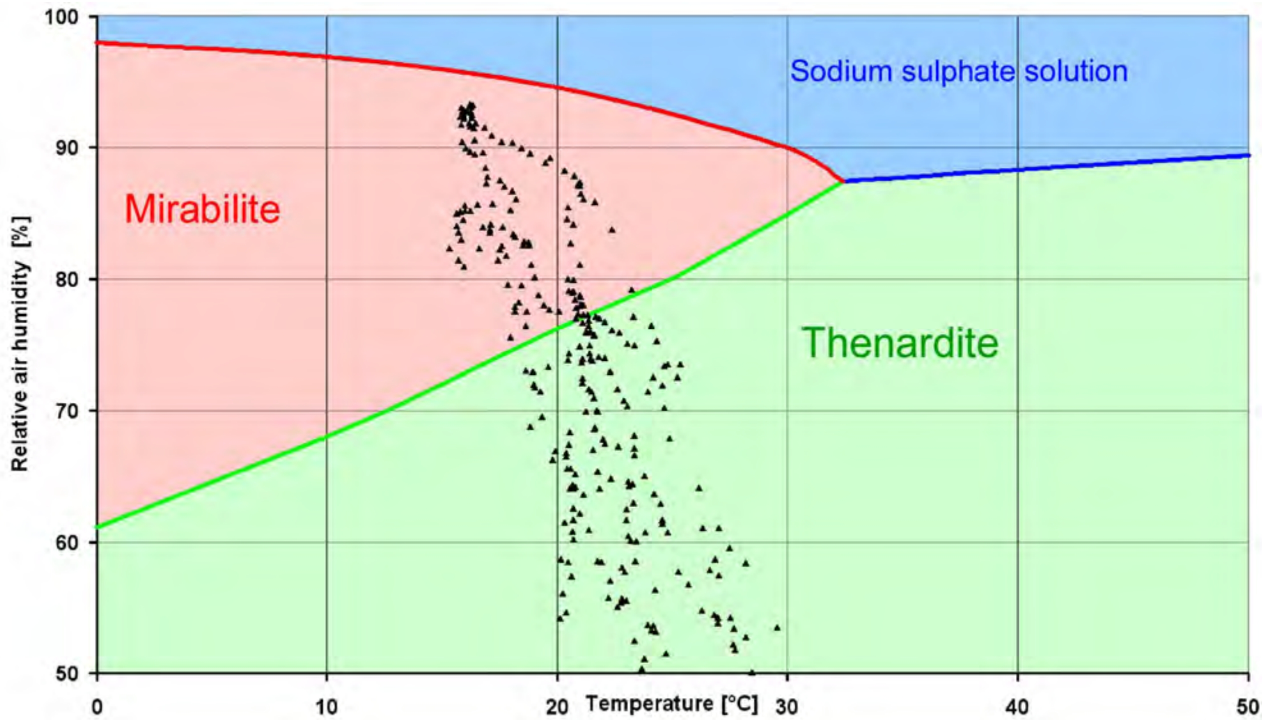



Fig. 2a The phase diagram sodium sulphate – water with plotted data points from Fig. 2b.

es in molar volume for the transformations of kieserite to starkeyite and hexahydrite to epsomite are 79 % and 10 %, respectively. Thenardite occurs very frequently in building materials.

**Figure 2a** shows the phase diagram sodium sulphate – water in which the univariant curve separating the thenardite from the mirabilite field defines the phase stabilities as a function of relative air humidity and temperature. For example, sodium sulphate is stable as mirabilite at 12.5 °C and above 70% relative air humidity, while at this temperature magnesium sulphate already occurs in the highest hydration stage as epsomite at 32% relative air humidity.

If the crystallisation and/or hydration pressure exceed the tensile strength of a building material, cracks will develop. The mechanical failure of a building material will not take place at the first crystallisation process but will be the effect of periodically repeated events with a gradual decline in material strength.

As pointed out above, sodium chloride and calcium sulphate are abundant at Al Zubarah. Therefore the occurrence of halite and thenardite in building materials is not surprising at all. From the recordings of climate data at Al Zubarah it is evident that the conditions for the crystallisation and deliquescence of halite and the transformation of thenardite to mirabilite and vice versa are real¬ised in the winter months, with peak humidities and temperature minima during the night hours [**Figure 2b**].

A special case of interaction of salts with building materials is the so-called sulphate attack, a reaction of calcium sulphate with Portland cement components or reaction products to form ettringite and/or thaumasite. The reaction of gypsum with water and tricalcium aluminate, a component of ordinary Portland cements, leads to the formation of ettringite, while the reaction of calcium sulphate, calcium carbonate, and water with calcium silicate hydrate phases, the hydration products of Portland cement, results in the formation of thaumasite. The increase in molar volume of the product over the reactants is 62.4% for the ettingite reaction and 75.7% for the thaumasite

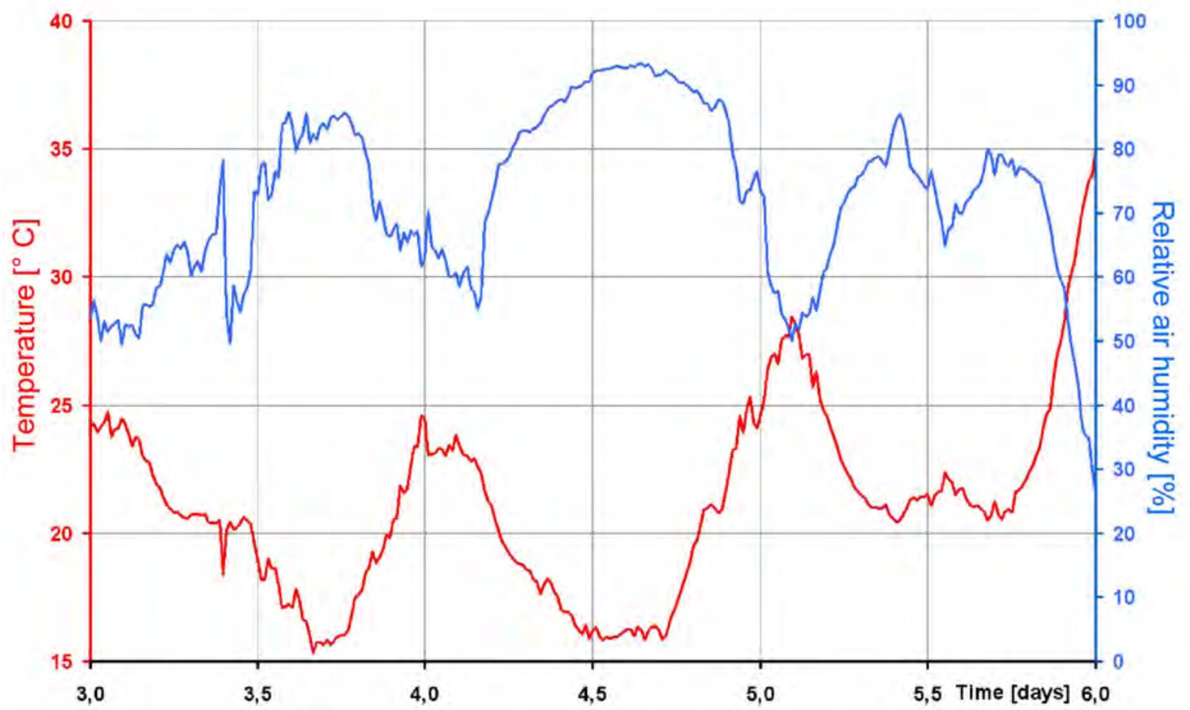



Fig. 2b : Temperature and relative air humidity data from 25.03.2012:12.00 to 28.03.2012:12.00.

reaction. Both reactions are harmful to building materials due to the volume increase. Laboratory tests with building materials from Al Zubarah have shown that there is a potential for ettringite and/or thaumasite formation. However, as the thaumasite reaction is favoured by low temperatures (T < 5 – 10 °C) which are uncommon in Qatar it is more likely that ettringite will be formed.

**5. What can we do with salts in building materials**

There is not so much we can do to suppress or stop the interactions of salts with building materials at Al Zubarah. We are restricted to mitigating harmful effects. A very simple but effective measure is the removal of salt efflorescences from wall surfaces with a brush. However, the brushed-off salts should not be discarded at the wall base but disposed of at a safe distance. The choice of binding materials which give sufficient strength to mortars to cope with the attack by crystallising and/or hydrating salts for at least several years will also help. As the salts are transported inside the walls from bottom to top by capillary forces it is recommended that we intercept the capillary rise of brines by a layer of impermeable building stones, such as the local dolomite at the wall base. However, this practice is only feasible when a wall requires a partial or total reconstruction. Finally, continuous maintenance of ma-sonry and renders will prevent small damages from becoming larger, so as not to endanger the stability of an entire structure.

Robert Sobott, December 2012

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# CHARACTERISTIC WEATHERING AND DECAY ATTESTED AT AL ZUBARAH ARCHAEOLOGICAL SITE

**Aeolian out-blow and Pluvial out-wash** of loose mortar and debris material
resulting in open joints, voids in wall structure, finally in instability and collapse of wall segments.

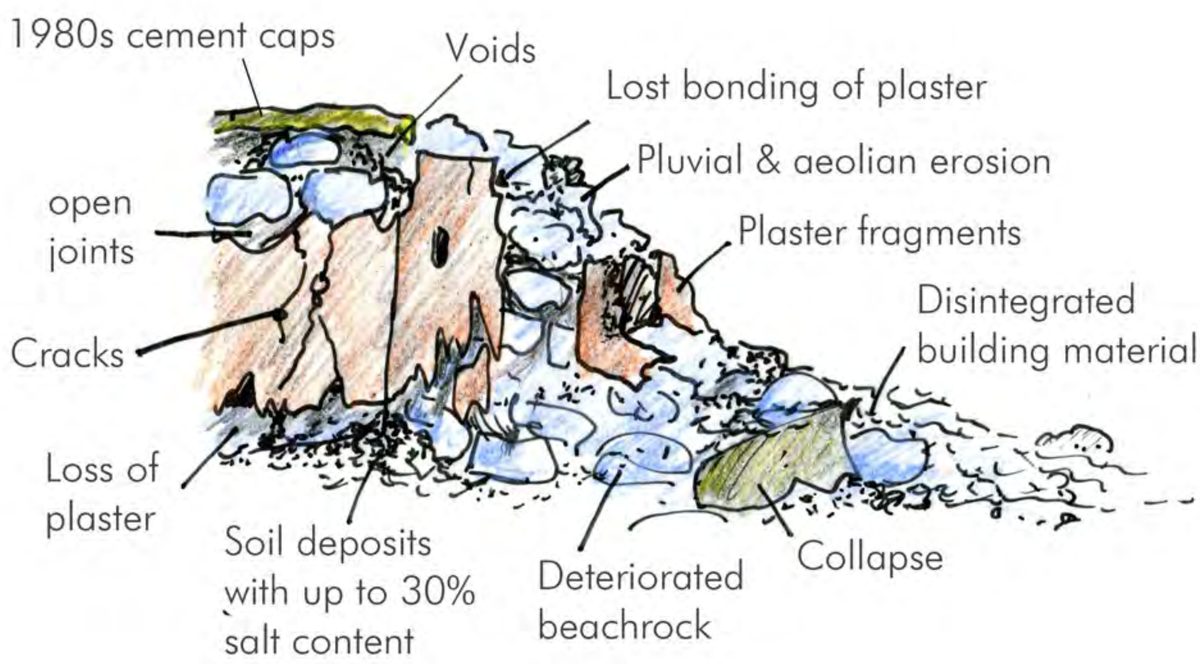
**Erosion, decay and disintegration** of single building materials components, e.g. for beachrock: Gastropods, molluscs, "sand", salts, etc. Especially wall bases and zones where salt containing sand/soil- deposits are located resulting in heavy damages of beachrock (salt crystallisation zone!)

**Bonding of plaster** to wall stones often limited or lost

**Plaster surfaces**: powdery or cracked due to fluctuation of temperature and humidity as well as volume changes of sulphates and salt crystals. beachrock decay reminds of mud brick deterioration processes

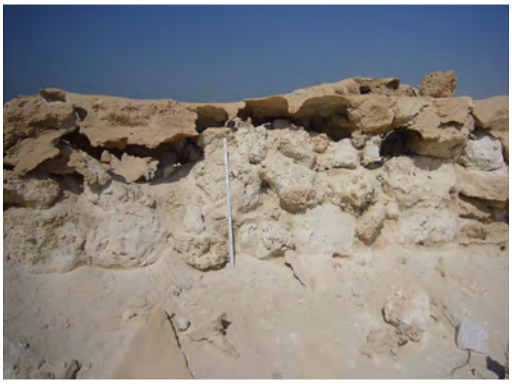
Instability of wall structures, due to insensitive repairs

Loss of wall structures due to **neglected maintenance**



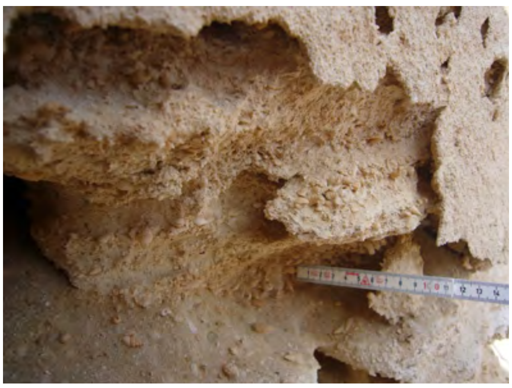
# HISTORIC BUILDING MATERIALS
## WEATHERING FORMS AND DETERIORATION PATTERN

Open joints (e.g. ZUEP04, wall 4010)



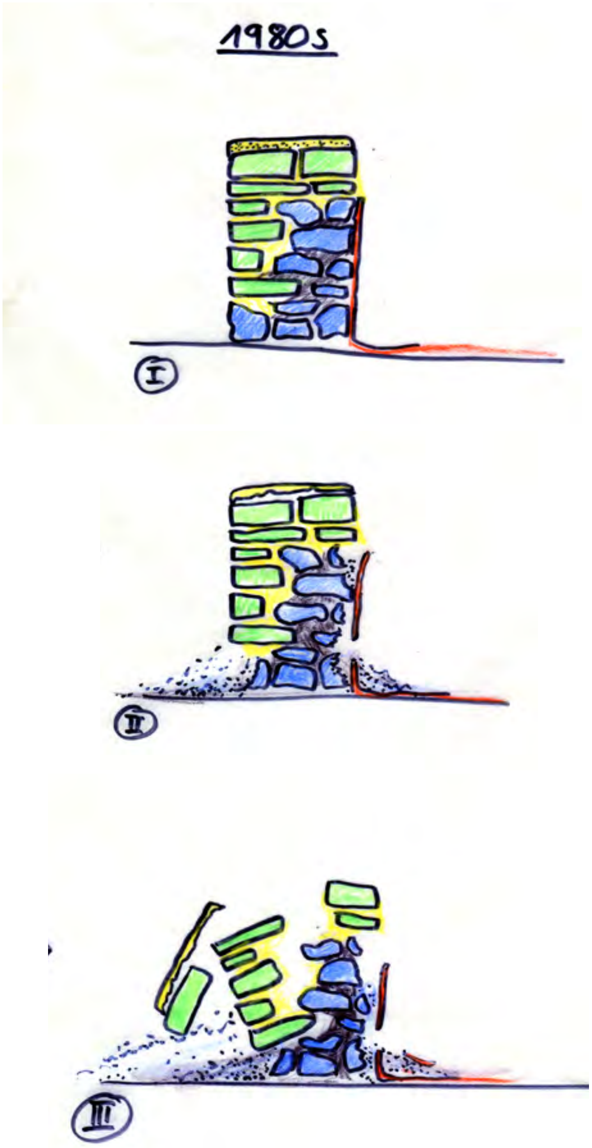
Eroded Beachrock (e.g. in QMA2)

Poor bonding of plaster to wall structure (e.g. QMA4:5c)



Voids in wall structures (e.g. QMA 4:4b)

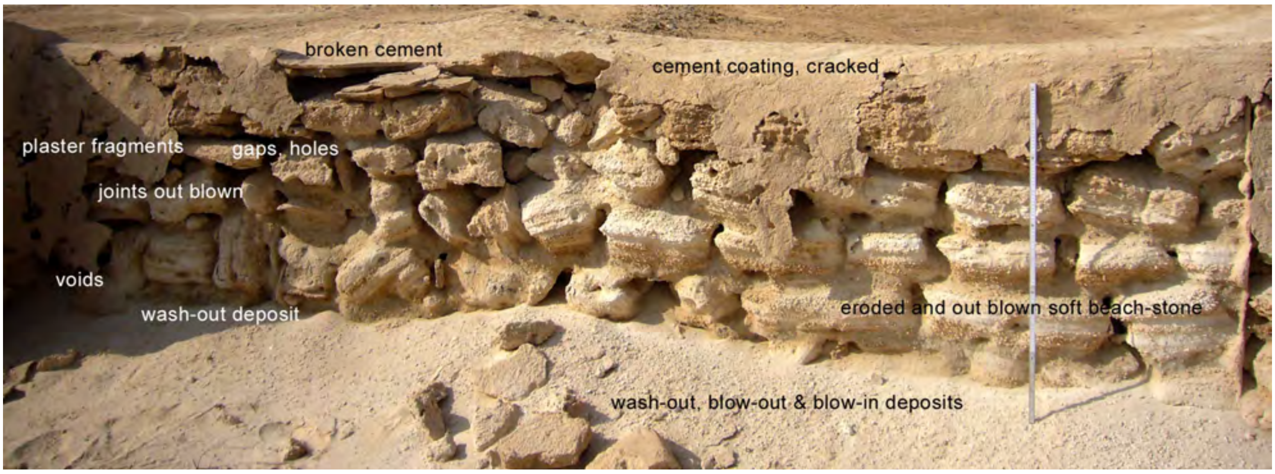
# GENERAL STATE OF CONSERVATION
IN EARLIER EXCAVATION AREAS

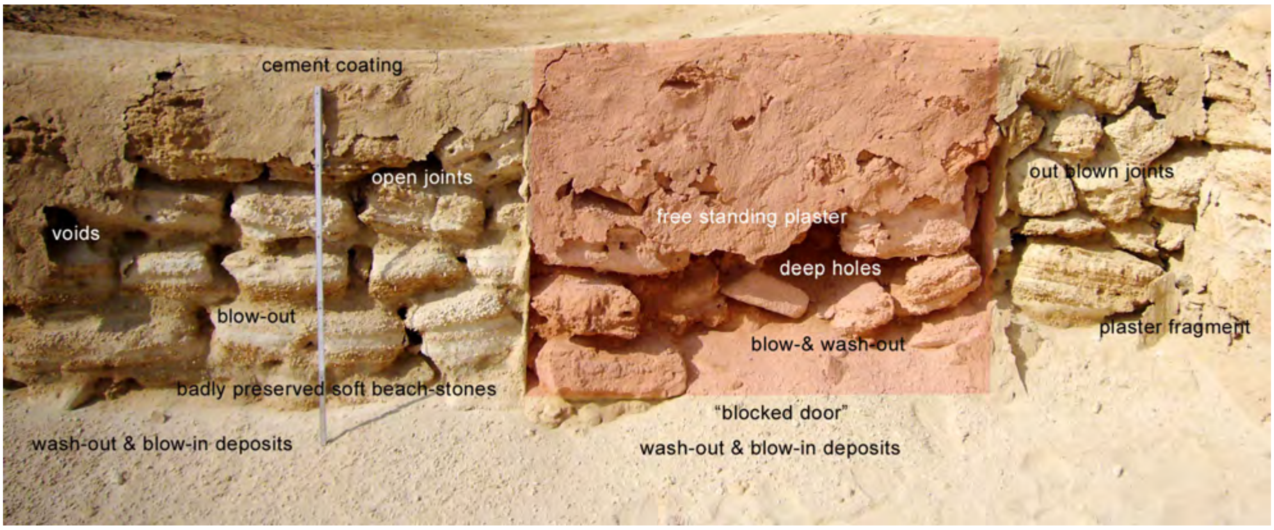


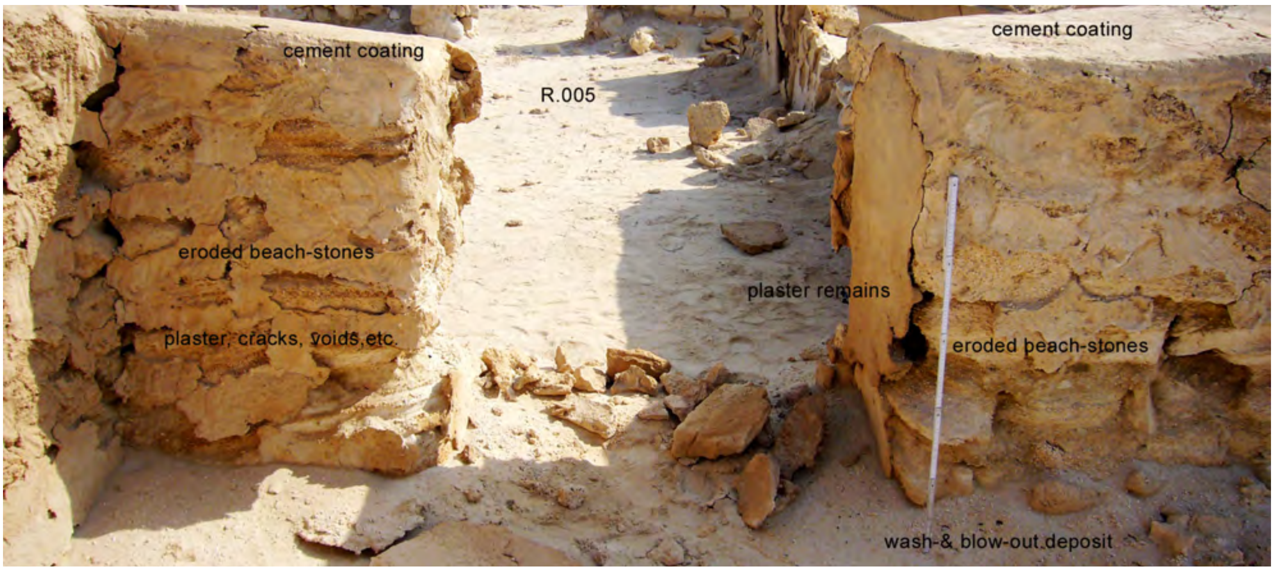

During the 1980s the first conservation measures took place following the archaeological excavations by QMA. The restoration work focused on the then excavated buildings (excavation areas QMA 1, 3 and 4) and on sections of the outer city wall (tower T6 to T10 and T15 to T16).

As part of these works, old wall stones were re-used to add courses to some walls to prevent further structural decay. Other walls, especially in area QMA 3, were more extensively reconstructed. In this restoration campaign traditional building and masonry techniques were used, however mortars were mainly cement-based, instead of local lime and gypsum-based mortars. In addition, most restored walls were capped with a cement coat. Lack of maintenance during the past twenty-five years and unsuitable materials has led to the substantial deterioration of the exposed walls. This earlier restoration project, which did not follow contemporary international standards, provides us with a useful reference tool. It offers invaluable data for the assessment of the decay rate of the exposed materials and a visual "proof" of the negative impact of cement-based mortars and cement capping on the walls.

# GENERAL STATE OF CONSERVATION
## EXAMPLES FROM QMA4 (FORTIFIED COMPOUND: ROOM 4)




State of conservation (QMA4) November 2009

# STATE OF CONSERVATION: TOWN WALL
## exposed segments

### 2009 - 2012

The town wall and its 23 towers were only exposed in two longer segments during the 1980s. The exposed parts of the wall as well as the towers were consolidated, re-built and partly reconstructed. Part of the exterior wall structure was completely re-built using cement mortar. The wall capping was also built with cement mortar. In some sections the dark grey portland cement layers are the only preserved element of the former wall structure, due to the extreme erosion of beachrock wall stones. Where joints are left open, voids can occur in the wall structure. Wall segments 6/7 to 9/10 show the greater impact of the strong north wind than do the exposed segments 16/17 to 18/19 in the southern part of the town.

Wall segment 8/9 **11/2011**

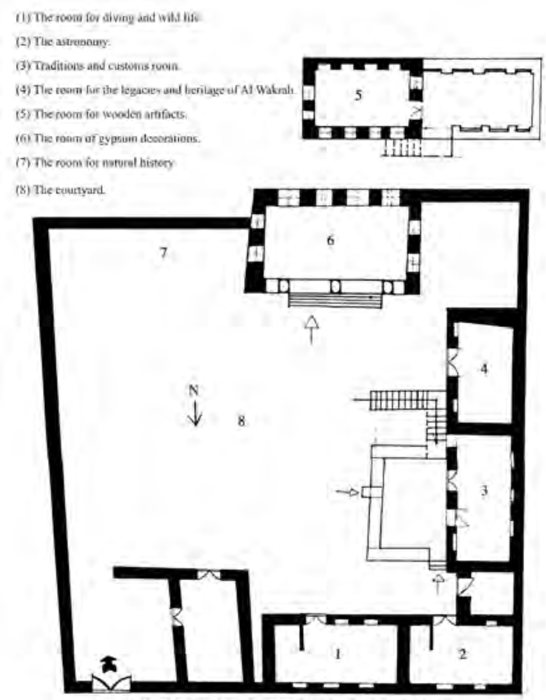
Wall segment 8/9 **12/2011**

Wall segment 8/9 **02/2012**

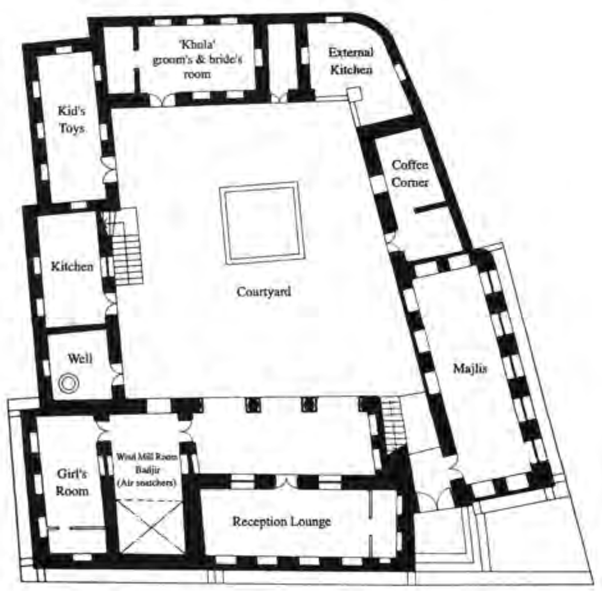
# ILLUSTRATED GLOSSARY: BUILDING TYPES
## TRADITIONAL BUILDINGS IN THE GULF REGION



### Courtyard houses




(Plate 24) The Layout of the ground floor and the upper room of the house. of Abdulla Saad Al-Mutlaq and the upper room is seen above -Wakrah

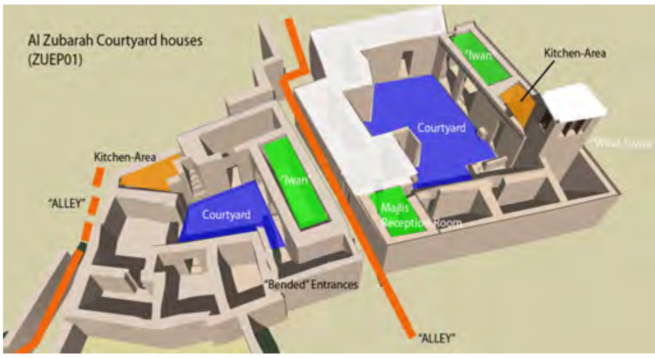



(Plate 25) Ahorizontal projection (Layout) of the ground floor of the house of Mohammed Saied Nasr Allah- (Doha)
Source: Doha Municipality Brochurre titled (Maltenance of the Architectural Heritage).

# ILLUSTRATED GLOSSARY: BUILDING TYPES
## TRADITIONAL BUILDINGS IN THE GULF REGION

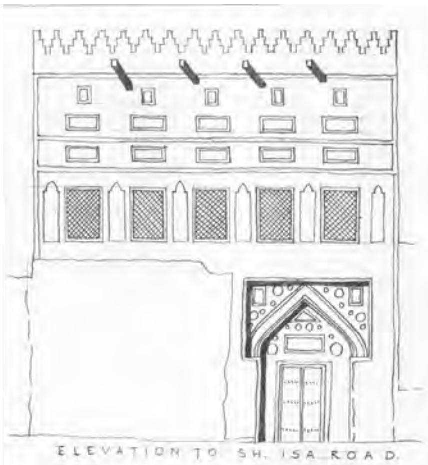
### Courtyard houses

Example from Al Zubarah




A - Courtyard
B - Bended Entrance
C - *Iwan* or *Majlis* (Reception hall)
D - Kitchen area
E - Private Courtyard with an *Iwan.*
F - Storage Room
G - Multipurpose room
H-Stair to upper level (roof)
J - Alley


Example from Abu Dhabi





Example from Qatar


Example from Wakra

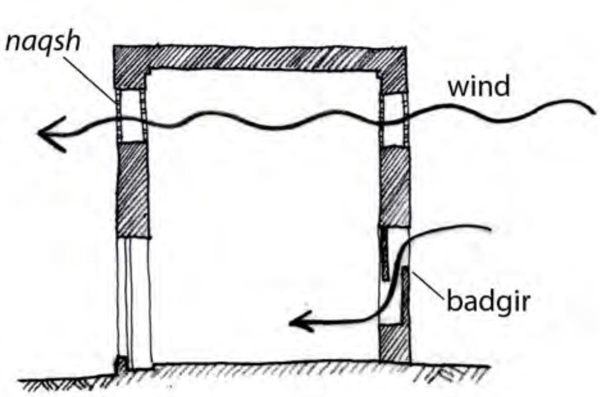

Example from Muharraq

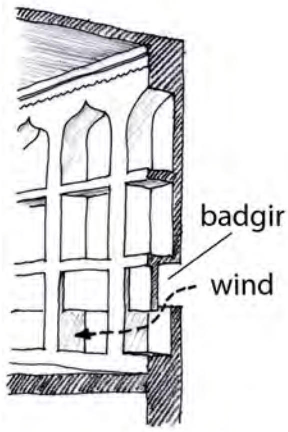
# ILLUSTRATED GLOSSARY: BUILDING TYPES

## TRADITIONAL BUILDINGS IN THE GULF REGION

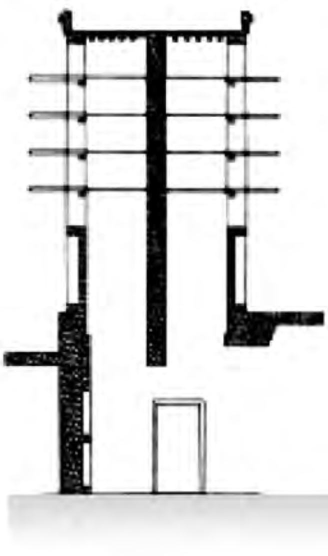
### Traditional air ventilation systems

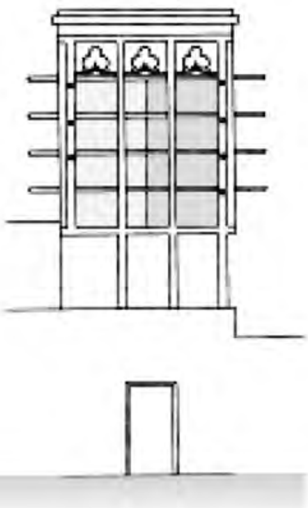
WIND CATCHER (Niches/Windows)



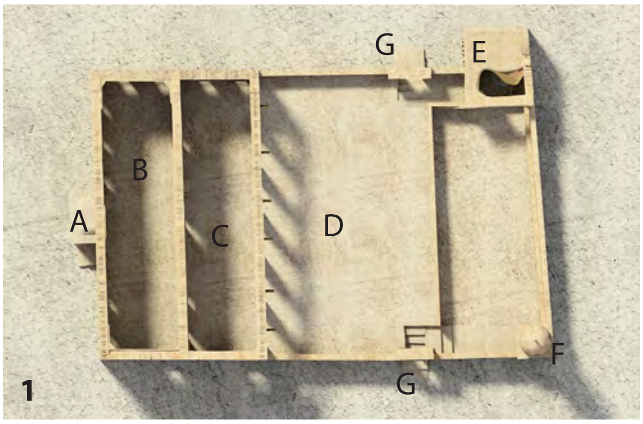

WIND TOWER (Badgir)

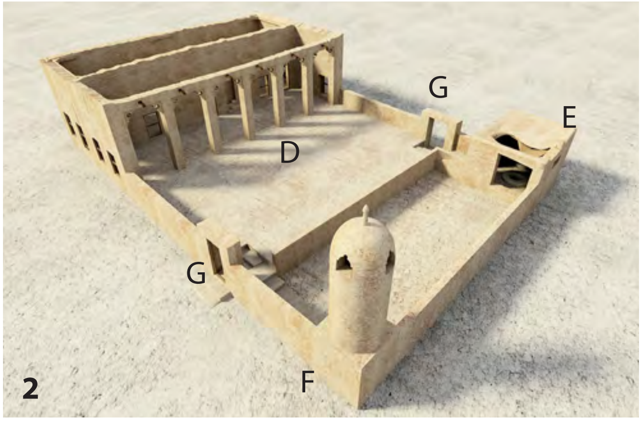




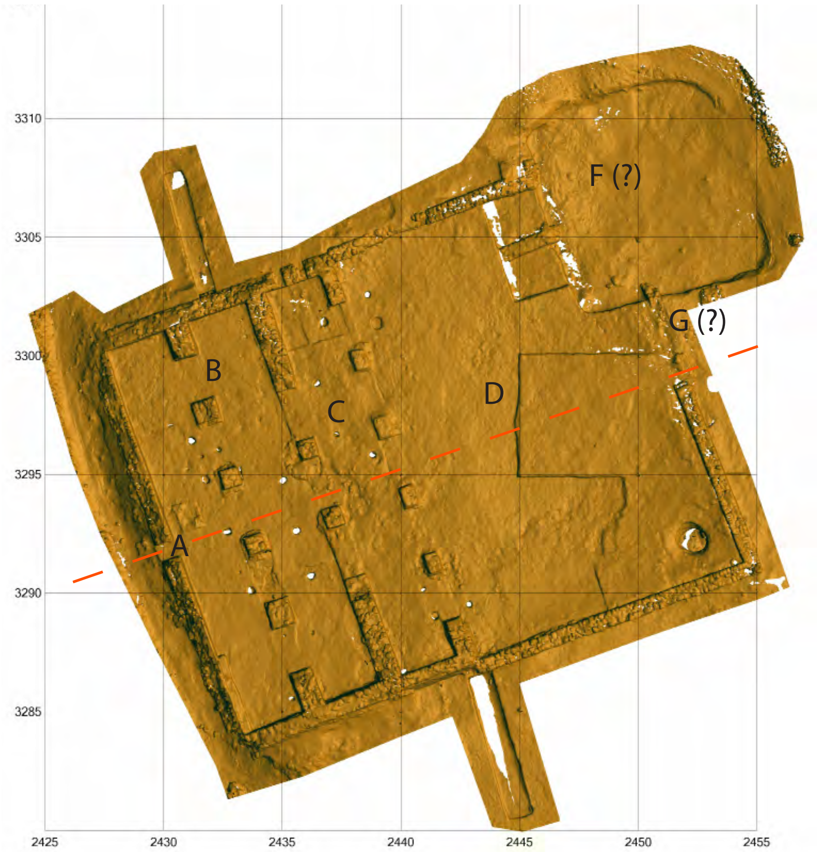
# ILLUSTRATED GLOSSARY: BUILDING TYPES
## TRADITIONAL BUILDINGS IN THE GULF REGION

### Mosque









Mosques:
1. Jumail Mosque; A - Mirhab & Minbar in Qibla wall, B - Prayer hall, C - Riwaq (?) / Portico, D - Courtyard (Sahar), E - Ablution-Room, F - Minaret, G - Entrances.
2. Jumail Mosque -Isometry.
3. Jumail Mosque - Combined Mirhab and Minbar.
4. Minaret at Al Arish.
5. Historic Mosque at Freiha (dashed line in red indicates Qibla direction); Labels as above.

# ILLUSTRATED GLOSSARY: BUILDING TYPES
## TRADITIONAL BUILDINGS IN THE GULF REGION

### Suq


Old suq in Qatar


Suq in Old - Kuwait


Suq in Old - Kuwait


Old suq waqif in Doha

The ***suq*** is a commercial building complex characterised by rows of shop stalls in narrow alleys passable only for pedestrians and pack animals. Stores of the same industries are often grouped together. In general, shops, only a few metres wide, open onto the alley. They can have storage, warehouses and workshops out the back and upstairs.

At Al Zubarah's suq (QMA1 / ZUEP02) *madbasas* are a common feature in the back of the shops. Roofs over the alleys of the suq, covered with wood and mats, protected pedestrians and goods. The rows of shops are complemented by warehouses and other commercial facilities, such as *khans*.


***Suq*** at Al Zubarah (QMA1/ZUEP02): rows of stores clearly visible. Structure and location was kept throughout the town's history.

# ILLUSTRATED GLOSSARY: BUILDING TYPES

## TRADITIONAL BUILDINGS IN THE GULF REGION

**Areesh (Arish)**
This was a summer house that would allow 'the weather to come in'. It was constructed from palm tree fronds mainly without leaves and with wide spacing between the fronds at ground level (up to 10 cm) to allow the wind to penetrate. The roof could be slightly pitched or flat. Characteristically the entire front of the rectangular enclosure would be open. Areesh buildings had no doors. Similar houses would be built up in the mountain oases for a single family to live in during their summer migrations to collect dates. This Areesh (Arish) typology is still used in the Fujairah mountains as a summer house for families who continue the tradition of summer migration.

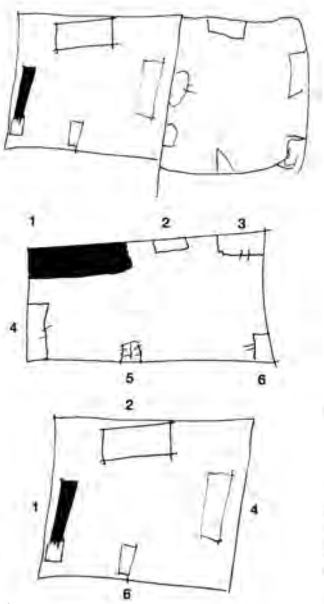
**Barasti**
English speakers often refer to any Arish building as a 'Barasti hut'. What the people of Hatta call barasti, however, is a rectangular building with a flat roof and a doorway in the middle of the front wall, constructed from an Arish frond, peeled of its leaves and put together in a pattern called sarabic, based on 10 cm by 10 cm spacing. Barasti buildings would always have hassir mats behind the Arish wall, where the air could not enter, and were sometimes used as majlis in the winter months of November to March. In some barasti interiors there was a small area designated as a bathroom (similar to khaimahs in the coastal and northern Emirates).

**Khaimah**
In all seven Emirates, the khaimah is a building with a pitched roof, used as a winter house and built totally from palm leaves woven tightly together in order not to allow cold wind or moisture to come through. In traditional khaimahs, including those of Hatta, the roof frame would always be constructed from a net of Arish fronds resting on a palm tree or chandel timber beam. The roof was covered with hassir mats and occasionally bitumen before the final layer of daan mats was applied. The interior of a khaimah would have sand, gravel or hassir mats on the floor. Internal walls might be covered with hassir mats, depending on the availability of materials and the status of the family.

**Kada**
Mountain regions offer a diverse source of building materials, stone in particular. The walls in kada buildings were built from stone, covered by palm leaves. They were used for storage or as family houses. Apart from Hatta, kada houses are found in the Al Hayl Palace areas of Fujairah Emirate.

Hatta heritage village, various styles of palm-leaf houses from the region, called (from top to bottom) Areesh, barasti, khaimah and kada, October 2009

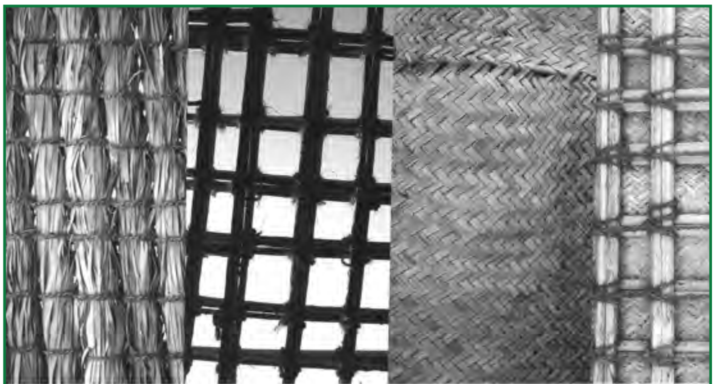
from: Piesik 2012:87




A typical house in Sharjah by Khaled Al Almari

1 Arish (summer house)
2 Khaimah (winter house)
3 Kitchen
4 Majlis for men
5 Entry
6 Bathroom

from: Piesik 2012:125



**kuse**
Palm frond (called zoor) with leaves intact

**sarabic**
Style of connecting palm-leaf fronds, usually into approximately 10 cm x 10 cm squares

**hassir**
Mat woven from palm leaves

**habel**
Linking rope. The combination of the palm fronds connected in the sarabic way with hassir mats behind is called barasti in Hatta

**Palm leaf weave typologies in Hatta**
Local names for some of the palm-leaf patterns.

from: Piesik 2012:88

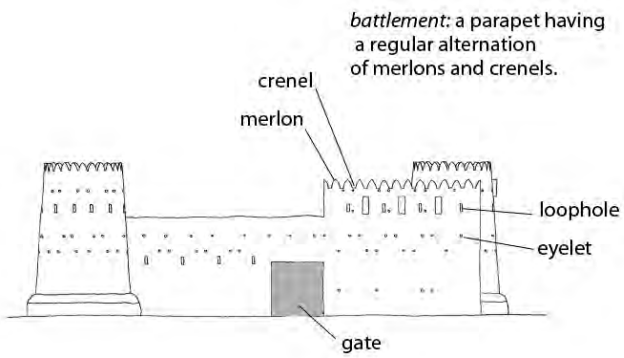
## Tents

## Forts

Al Zubarah Fort

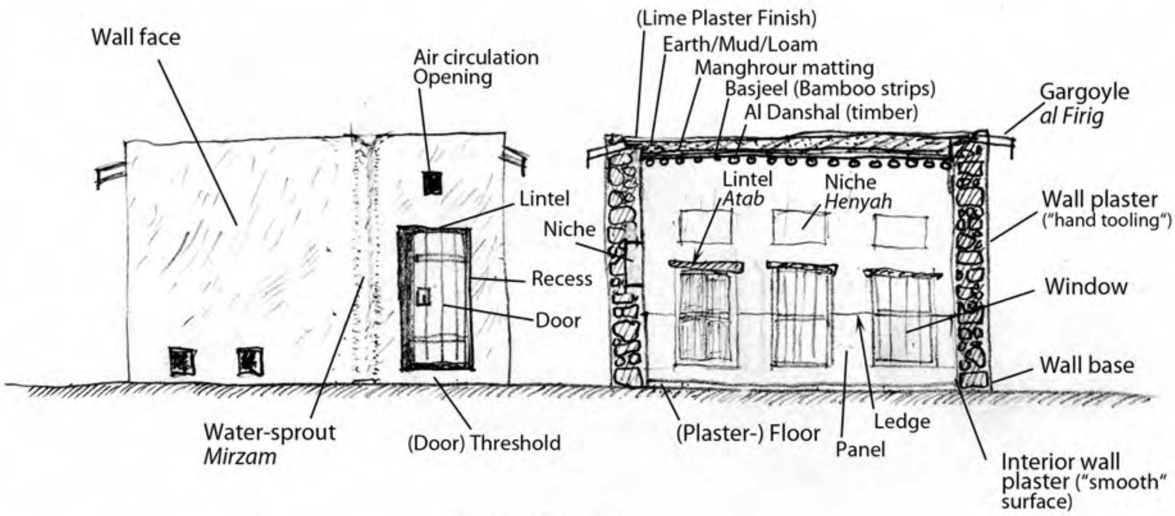
Al Thagab

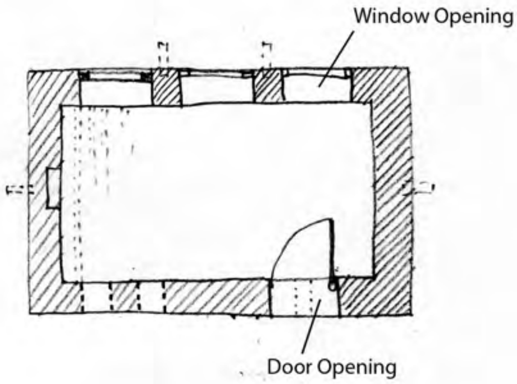
Rakayat



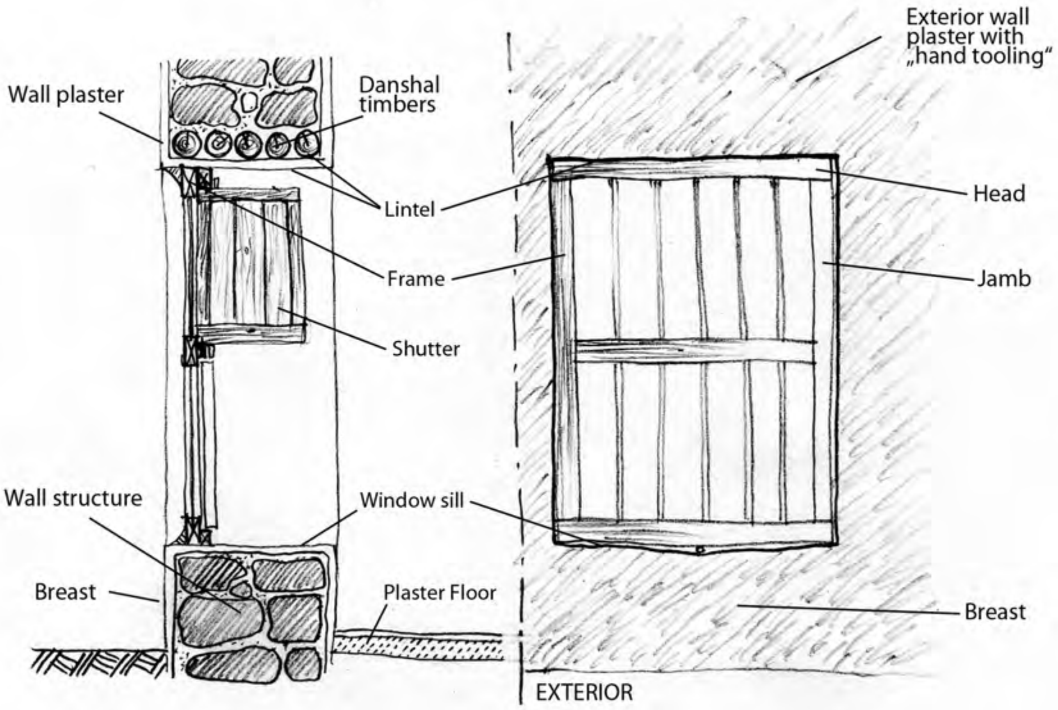

# ILLUSTRATED GLOSSARY: BUILDING TERMS

ENGLISH

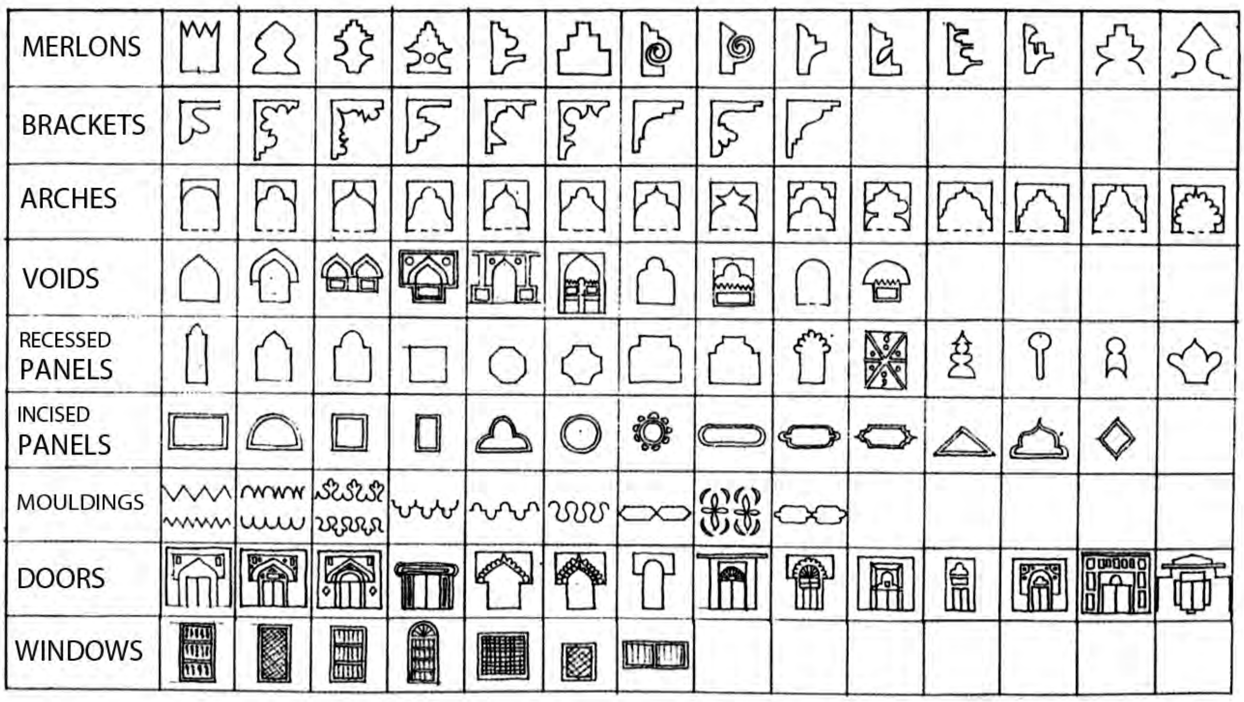


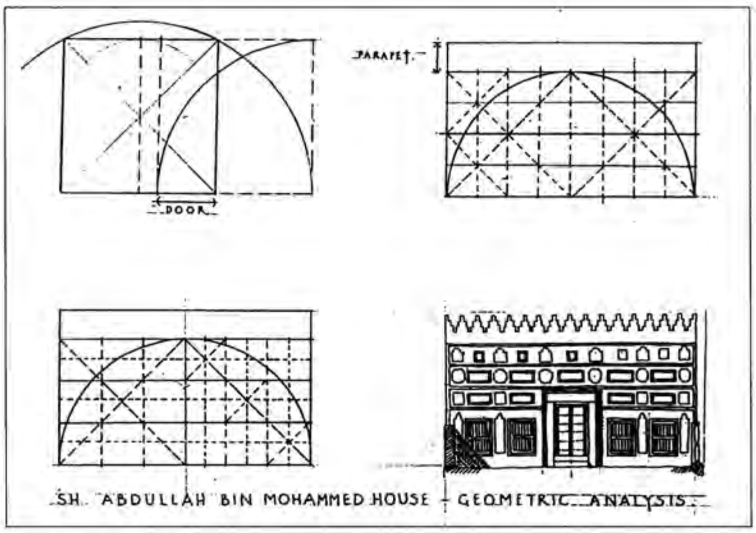



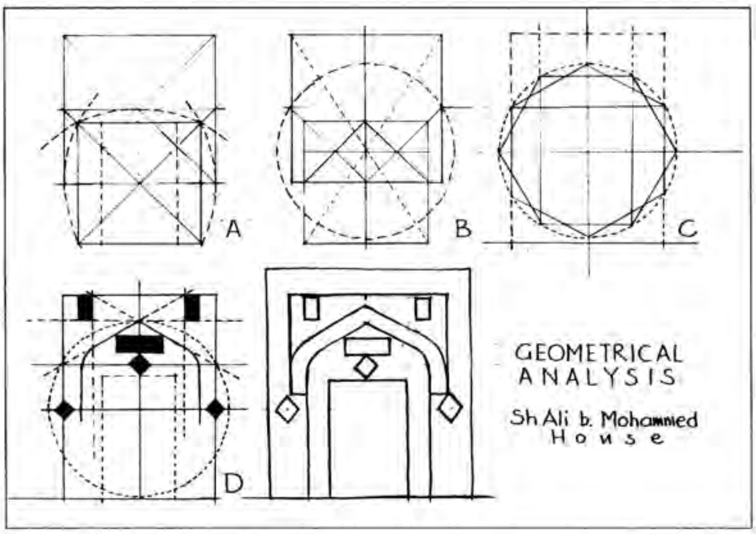

WINDOW



# DECORATION PATTERNS & PROPORTIONS



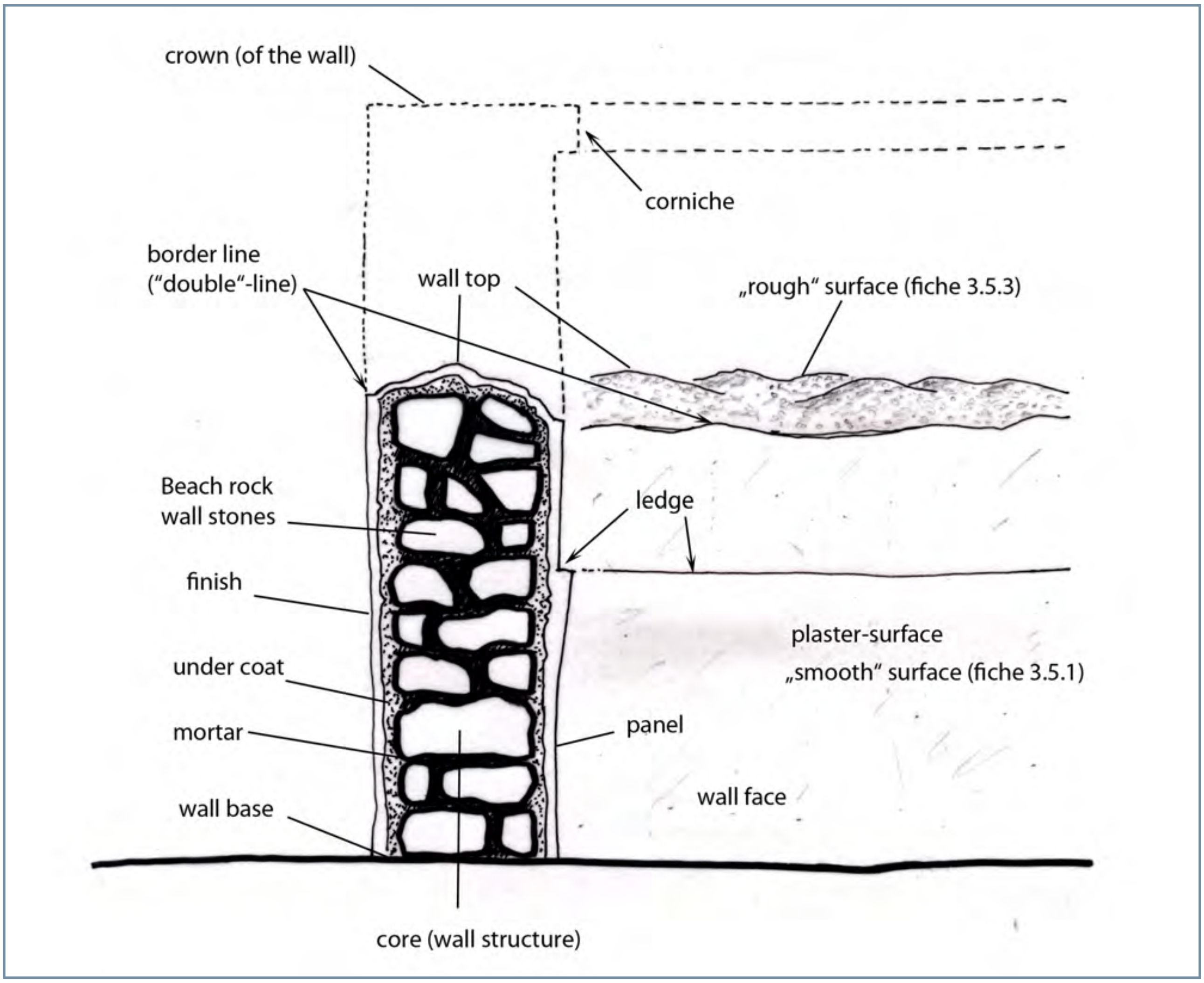




after Yarwood & El-Masri 2006: Fig.2.4

# ILLUSTRATED GLOSSARY: BUILDING TECHNOLOGY

ENGLISH

# ILLUSTRATED GLOSSARY: BUILDING MATERIALS


1 - (Quartz) sand

2 - Al Danshal timber from East Africa

3 - Basjeel, bamboo strips (from India)

4 - Daoun, Palm leaf mats (from the Emirates)

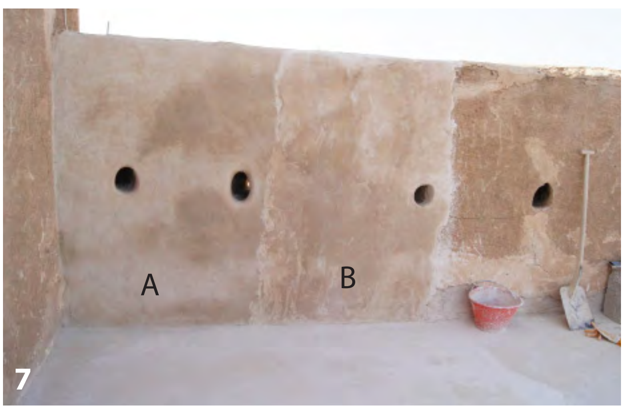
5 - Manghrour matting

6 - Soil/ Earth / Mud

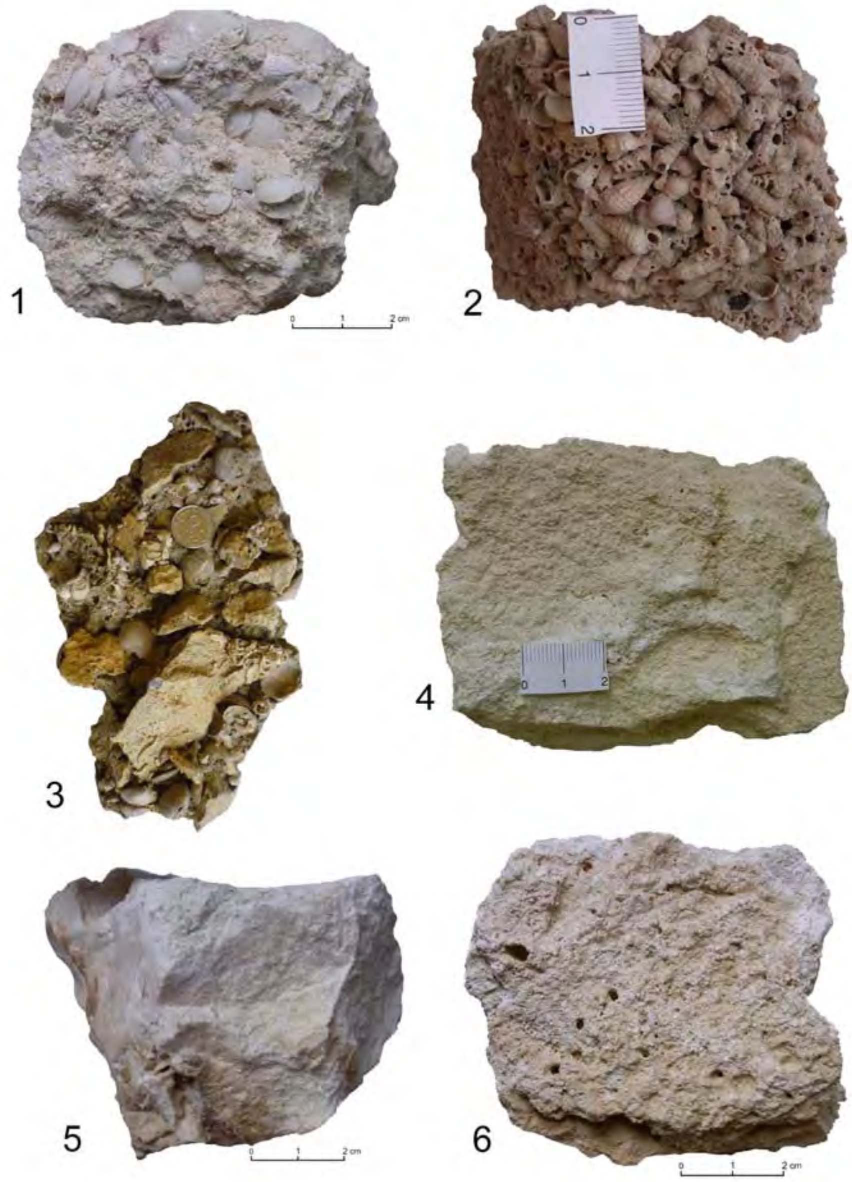
7 - Plaster materials (Lime [A] & Gypsum [B]-based)





# ILLUSTRATED GLOSSARY: BUILDING MATERIAL -Rock types
ENGLISH




**ROCK TYPES USED IN WALLS AT AL ZUBARAH**

1: Beach rock - mollusc rudstone (AG);
2: Beach rock - gastropod rudstone (BJ);
3: Conglomerate (KA or LA);
4: Aeolianite (FR);
5: Dolomitic limestone (BL);
6: Gypsum rock (BE)

For an identification scheme see fiche 2.2, 6.1 or Appendix 1

# ILLUSTRATED GLOSSARY: DETERIORATION PATTERNS
## ENGLISH, German

### GENERAL TERMS . ALLGEMEINE BEGRIFFE

**ALTERATION** . MATERIALVERÄNDERUNG
**DAMAGE** . SCHADEN
**DECAY** . ZERFALL (VERFALL)
**DEGRADATION** . ABBAU, VERSCHLECHTERUNG
**DETERIORATION** . ZERSTÖRUNG, SCHÄDIGUNG
**WEATHERING** . VERWITTERUNG

### CRACK & DEFORMATION
RISS(E) & VERFORMUNG(EN)

**CRACK** . RISS
- **Fracture** . Bruch
- **Star crack** . Sternförmig verlaufende Risse
- **Hair crack** . Haarriss
- **Craquele** . Craquelé
- **Splitting** . Aufspalten

**DEFORMATION** . VERFORMUNG

### DETACHMENT
ABLÖSUNG

**BLISTERING** . BLASENBILDUNG, AUFWÖLBUNG

**BURSTING** . AUSBRUCH (AUSBRECHEN)

**DELAMINATION** . SCHICHTSPALTUNG
- **Exfoliation** . Aufblättern

**DISINTEGRATION** . ZERFALL IN GESTEINSPARTIKEL
- **Crumbling** . Abbröckeln
- **Granular disintegration** . Körniger Zerfall
  - **Powdering, Chalking** . Abmehlen, Kreiden
  - **Sanding** . Absanden
  - **Sugaring** . Zuckerkörniger Zerfall

**FRAGMENTATION** . ZERBRECHEN
- **Splintering** . Abscherben
- **Chipping** . Absplittern

**PEELING** . ABSCHÄLEN (DÜNNE SCHALE)

**SCALING** . ABSCHALEN
- **Flaking** . Abschuppen
- **Contour scaling** . Schale oder Konturschale

### FEATURES INDUCED BY MATERIAL LOSS
FORMEN DES MATERIALVERLUSTS

**ALVEOLIZATION** . ALVEOLENBILDUNG
- **Coving** . Aushöhlung

**EROSION** . EROSION
- **Differential erosion** . Differentielle Erosion
- **Loss** . Verlust :
  - **of components** . von Komponenten
  - **of matrix** . von Matrix
- **Rounding** . Zurundung
- **Roughening** . Aufrauung

**MECHANICAL DAMAGE** . MECHANISCHER SCHADEN
- **Impact damage** . Einschlagschaden
- **Cut** . Einschnitt
- **Scratch** . Kratzer
- **Abrasion** . Abrieb
- **Keying** . Aufspitzen

**MICROKARST** . MIKROKARST

**MISSING PART** . FEHLSTELLE
- **Gap** . Lücke

**PERFORATION** . PERFORATION, DURCHLÖCHERUNG

**PITTING** . PITTING (GRUBE)

### DISCOLORATION & DEPOSIT
VERFÄRBUNG & ABLAGERUNG

**CRUST** . KRUSTE
- **Black crust** . Schwarze Kruste
- **Salt crust** . Salzkruste

**DEPOSIT** . ABLAGERUNG

**DISCOLOURATION** . VERFÄRBUNG
- **Colouration** . Färbung
- **Bleaching** . Bleichung
- **Moist area** . Feuchtezone
- **Staining** . Fleckenartige Verfärbung

**EFFLORESCENCE** . AUSBLÜHUNG

**ENCRUSTATION** . INKRUSTATION
- **Concretion** . Konkretion

**FILM** . FILMBILDUNG

**GLOSSY ASPECT** . GLANZ

**GRAFFITI** . GRAFFITI

**PATINA** . PATINA
- **Iron rich patina** . Eisenreiche Patina
- **Oxalate patina** . Oxalatpatina

**SOILING** . VERSCHMUTZUNG

**SUBFLORESCENCE** . SUBFLORESZENZ

### BIOLOGICAL COLONIZATION
BIOLOGISCHE BESIEDLUNG

**BIOLOGICAL COLONIZATION** . BIOLOGISCHE BESIEDLUNG

**ALGA** . ALGEN

**LICHEN** . FLECHTEN

**MOSS** . MOOSE

**MOULD** . SCHIMMEL (PILZE)

**PLANT** . PFLANZE

ICOMOS (ed.)
2010 Illustrated Glossary on stone deterioration patterns. English-german version. Translation by Rolf Snethlage, Stefan Simon und Kurt Heinrichs. Petersberg: Michael Imhof Verlag. p.7.

# GLOSSARY: DETERIORATION PATTERNS

## ENGLISH, German

| ENGLISH | German |
|---|---|
| **ALTERATION**<br>Modification of the material that does not necessarily imply a worsening of its characteristics from the point of view of conservation. For instance, a reversible coating applied on a stone may be considered as an alteration. | **MATERIALVERÄNDERUNG**<br>Veränderung der Materialeigenschaften, die nicht notwendigerweise eine Verschlechterung des Zustands unter dem Gesichtspunkt der Konservierung bedeutet. Ein reversibler Überzug auf einem Gestein kann zum Beispiel als eine Materialveränderung betrachtet werden. |
| **DAMAGE**<br>Human perception of the loss of value due to decay. | **SCHADEN**<br>Menschliche Wahrnehmung des Wertverlusts durch Verfall. |
| **DECAY**<br>Any chemical or physical modification of the intrinsic stone properties leading to a loss of value or to the impairment of use. | **ZERFALL / VERFALL**<br>Jede chemische oder physikalische Veränderung der Gesteinseigenschaften, die zu einem Wertverlust oder einer Einschränkung der Gebrauchsfähigkeit führt. |
| **DEGRADATION**<br>Decline in condition, quality, or functional capacity. | **ABBAU / VERSCHLECHTERUNG**<br>Negative Veränderung des Gesamtzustands, der Qualität oder Funktionalität. |
| **DETERIORATION**<br>Process of making or becoming worse or lower in quality, value, character, etc.; depreciation. | **ZERSTÖRUNG / SCHÄDIGUNG**<br>Prozess, welcher die Verschlechterung des Materialzustands, die Minderung der Qualität oder des Werts oder des Materialcharakters verursacht oder der Prozess der Verschlechterung/des Zerfalls selbst. |
| **WEATHERING**<br>Any chemical or mechanical process by which stones exposed to the weather undergo changes in character and deteriorate. | **VERWITTERUNG**<br>Jeder chemische oder mechanische Prozess, durch den Gesteine, die der Witterung im Freien ausgesetzt sind, Veränderungen ihrer Eigenschaften erfahren und zerfallen. |

ICOMOS (ed.)
2010 Illustrated Glossary on stone deterioration patterns. English-german version. Translation by Rolf Snethlage, Stefan Simon und Kurt Heinrichs. Petersberg: Michael Imhof Verlag. p.8.

# ILLUSTRATED GLOSSARY: DETERIORATION PATTERNS
## ENGLISH, German

**ALTERATION** . MATERIALVERÄNDERUNG

Common **alteration** of architectural mouldings by algae.

**Materialveränderung** von Architekturprofilen durch Algen.

*Scotland, Edinburgh, Meadows Pillars, 1992. Height of vertical face approx. 300mm. Pers. Archive (ref. KP 22) / I. Maxwell*

**DEGRADATION** . ABBAU / VERSCHLECHTERUNG

**Degradation** of red sandstone masonry due to defective rainwater gutter behind parapet.

**Verschlechterung/ Minderung** des Erscheinungsbildes eines roten Sandsteinmauerwerks durch schadhafte Regenrinne oberhalb des Gesimses.

*Scotland, Edinburgh, Caledonian Hotel, 1991. Individual block heights approx. 300mm. Pers. Archive (ref. KD 30) / I. Maxwell*

**DAMAGE** . SCHADEN

**Damage** to the lower part of a sandstone grave slab resulting in loss of value.

Einen Wertverlust verursachender **Schaden** am unteren Teil einer Grabplatte aus Sandstein.

*Scotland, Edinburgh, Old Calton Cemetery, 2002. British Geological Survey / E. Hyslop*

**DETERIORATION** . ZERSTÖRUNG / SCHÄDIGUNG

**Deterioration** of a Carboniferous sandstone masonry.

**Schädigung** eines Mauerwerks aus Karbonsandstein.

*Scotland, Edinburgh, North Castle Street, 1993. Individual block heights approx. 30cm, Pers. Archive (ref. OU 13) / I. Maxwell*

**DECAY** . ZERFALL / VERFALL

Limestone relief showing advanced **decay**.

Kalksteinrelief im Zustand fortgeschrittenen **Verfalls**.

*France, Caen, Eglise Saint-Pierre, 2006. head ca.10 cm, LRMH / V. Vergès-Belmin*

**WEATHERING** . VERWITTERUNG

**Weathering** of a Lewisian Gneiss monolith resulting from long term exposure to the elements.

**Verwitterung** eines Monoliths aus Lewisian Gneis durch lange Klimaexposition.

*Scotland, Isle of Lewis, Tursachan Stone Circle, Callanish, 1990. Width of stone approx. 1.2m . Pers. Archive (ref. GH 9) / I. Maxwell*

ICOMOS (ed.)
2010 Illustrated Glossary on stone deterioration patterns. English-german version. Translation by Rolf Snethlage, Stefan Simon und Kurt Heinrichs. Petersberg: Michael Imhof Verlag. p.9.

# GENERAL ACTION PLAN: CONSERVATION SCHEME

## 1. BASICS (PART 1)

a) **Decay processes**, deterioration of building materials, climate conditions, state of conservation.

b) **Recording & Monitoring** (3D-Laser scanning, photo, sketch, drawing, text, Inventory), Documentation, includes mapping, etc.

c) **Analyses,** assessment and evaluation of structural conditions.

Conservation Inventory

Walls

Room No: 0001 Wall ID: 128 Wall: a Back to Room

View of the wall a (northern wall).

| Max. Height | Min. Height | Courses No. | Width | Wall Lenght |
|---|---|---|---|---|
| 1,00 m | 0,60 m | 5 | 0,60 m | 11,20 m |

Building Materials: Agneta, Bille 1, Frida; ☑ Benny, ☐ Björn, ☐ Kalle

Mortar: ☑ Anhydride/Lime, ☑ Mud, ☑ Cement, ☐ Other

Plaster: ☑ Anhydride/Lime, ☐ Mud, ☐ Soil, ☐ Cement, ☐ Other

Damages: ☑ Yes, ☐ No

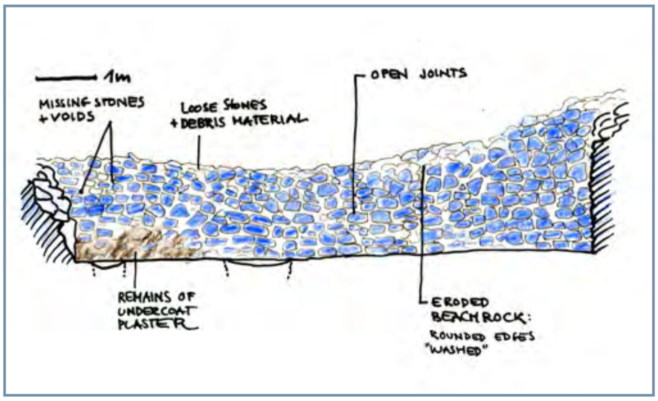
Measures: ☑ Required, ☐ Not required

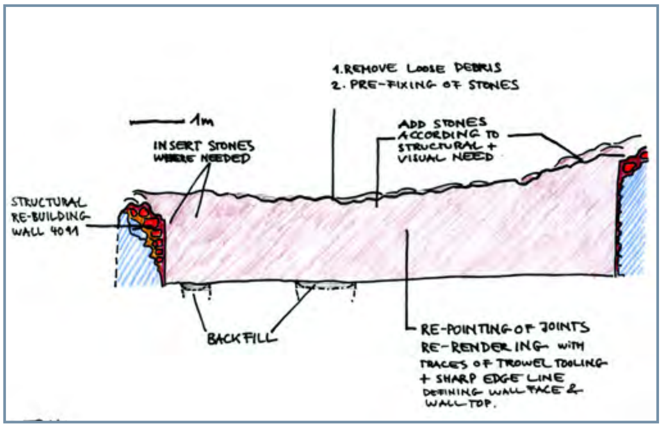
Date: 18.11.2009 Date of data modification: 08.01.2011

Data entered by: Moritz Kinzel Data modified by: Bernadeta Schäfer

## 2. PLANNING (PART 2)

d) **Planning** of measures according to assessment of state of conservation. Plan sketches to discuss stragtegies. Concept development; Selection and test of materials. Definition of conservation scheme and technical solutions (*Fiches techniques*)




## 3. IMPLEMENTATION (PART 3)

e) **Fiches Techniques** as step by step instructions; listing of needed materials, tools, required staff, premises, climate conditions etc.


FICHE No.4.3

CONSOLIDATION OF PLASTER
Cementing of cracks and loose plaster parts

FIELD OF APPLICATION: general
Climate conditions:
PREMISE: Fiche No. 4.1 has to be executed before!
PERSONNEL: One or two skilled restorer
TOOLS: Brushes, Industrial hoover, spatulae, trowel, bucket, sponge,
MATERIALS: Water, acryl-dispersion
EXTRA: Avoid direct sun and too strong winds
Einsatzgebiet: generell, Anwendung jedoch nur bei Wind bis max 5 Bft und max. 28°C

Fiche No. 4.3 cementing of cracks and lost inner plaster parts
Vorrausetzung ist abgearbeiteter Fiche No. 4.1 !

Einsatzgebiet: generell, Anwendung jedoch nur bei Wind bis max 5 Bft und max. 28°C

!Bitte die Kartierung (in EP04), die ich mal gemacht habe mit reinstellen, um die Grenzen zwischen Putz und Putzsicherung deutlich zu machen.

1. Reinigen der Putzgrenzen mit Pinsel, Staubsauger, Lanzette (Foto 4301, 4302)
2. Herstellen Putzmischung (1RT wLh, 4 RT ds, 2%SF016 in Anmachwasser) in Mengen, die auch innerhalb von 1 Std. verarbeitet werden können Foto 4303)
3. Auftrag nach vorfeuchten auf historisches Putzniveau, Schließen von Löchern und Rissen, Übergang zum späteren Verputz herstellen. (Fotos 4304, 4305, 4306)
4. nach ca. 10-30 min. Nachbehandlung mit Schwamm, dabei Freiwaschen der Körnung, Glättung und Reinigung der Putzgrenzen (Foto 4307)
5. Schütze deinen Arbeitsabschnitt ! mindestens 12 Std. Schutz des Arbeitsabschnittes vor Wind und Sonne (Foto 4308), dabei immer Nachfeuchten (kein Foto)

Note: Ziel der Maßnahme ist die Stabilisierung der Putzoberflächen durch Schließen von Löchern und Rissen im historischen Putz. Die Grenze zur Putzkante Neuverputz (Fiche 3.5) ist vorher mit dem Planer festzulegen.

FICHE No.4.3

CONSOLIDATION OF PLASTER
Cementing of cracks and loose plaster parts

## 4. DECAY PROCESS

f) Decay and deterioration of materials caused by natural and human agency. Restart of process (see Part 1).

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PART 2

# CONSERVATION CONCEPT

## PRESERVATION OF RUINS
## REALISING ARCHITECTURE

2

**Conservation Handbook for Al Zubarah Archaeological Site - PART 2**
Edited by Moritz Kinzel with contributions by Simone Ricca, Paul Hofmann and Robert Sobott.
First Edition January 2013 QIAH-01-02-HE-1000. DOHA /COPENHAGEN 2013
ISBN 978-87-89221-08-3

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University of Copenhagen and the Qatar Museums Authority - Al Zubarah Archaeological Site.

# CONSERVATION CONCEPT GENERAL PRINCIPLES

## INTRODUCTION

The excavations at Al Zubarah are among the largest ongoing excavations in the world. The research and excavation programme started in 2009 has taken into consideration the issue of the conservation of the uncovered vestiges and of the archaeological finds since the beginning of the operations on the field.

While an important series of analyses and tests on building material was carried out during the first years to determine a preliminary strategy of intervention, QMA and QIAH realised that a comprehensive concept capable of dealing with the extraordinarily complex issues conservationists have to confront in Al Zubarah was needed.

In order to design such a strategy, a seminar, gathering a panel of international experts in archaeological conservation, was organised in Doha between 29 November and 2 December 2011. This first meeting will be followed by similar seminars in the coming years and the panel of experts is meant to become an "international committee" for the preservation of Al Zubarah, advising the QIAH project and reviewing the results achieved on site.

The involvement of international experts and the scientific discussions into the ongoing works are a proof of the QIAH commitment and are in full compliance with the state-of-the-art approaches to conservation and site management outlined in the UNESCO Nomination File and Management Plan.

## A COMPREHENSIVE STRATEGY: CONCEPTS AND DRIVING PRINCIPLES

The conservation of an entire city buried under the sand of the Qatari desert, in one of the most challenging climates of the world and set in an extremely salty natural environment, imposes the definition of clear principles to direct the intervention. These principles should be translated into flexible technical solutions capable of adapting to the results of the ongoing excavations, studies and experiments.

The QIAH Team in charge of the conservation of Al Zubarah has followed a step-by-step approach in order to adapt the interventions to the data being collected and to the results of the archaeological excavations. The conservation activities carried out in Al Zubarah Archaeological Site can be divided into three successive phases, each one building upon the previous one.

**Phase 1**
Data collection: analysis of the building materials and techniques, review of the climatic and physical conditions on site, tests and preliminary interventions on the built structures.

**Phase 2**
Design of a conservation strategy based upon the use of lime mortars. On the basis of the scientific data collected in phase 1, the team has defined a set of solutions and a series of building materials and techniques adapted to Al Zubarah. Particular emphasis has been put on the use of local sands and soil, and on the analysis of the tooling and building techniques used in the past.

**Phase 3**
While continually implementing the principles of Phase 2, the conservation team will further explore the possibilities related to the use of anhydrate mortars and plasters. Laboratory exams, on-site tests and visits to other archaeological sites in the region will allow us to design more "sustainable" building materials that may withstand the extreme climatic conditions of the present-day ruined city of Al Zubarah.

The Manual details the solutions of Phase 2, constituting a coherent conservation strategy for the site. These solutions might be modified according to the development of Phase 3 in further updated versions of this document.

The methodological approach followed during the first two years of the campaigns for the conservation of Al Zubarah was driven by the will to "improve" the materials found on the site. It was mainly based upon laboratory analyses, with the emphasis put on chemical and physical data, to design new improved mortars and masonry solutions. Such an approach implied that non-traditional materials (white cement, hydraulic limes, clean salt-free quartz-sands) be used to "freeze" the situation and reduce the disruptive impact of salt crystallisation on both mortars and stones.

The laboratory analyses carried out in this preliminary phase have enabled us to get a clear picture of the characteristics of the stones and mortar used by Zubarah's builders and to make a precise classification of the building materials used in Al Zubarah (cf. Appendix 1 and 2).

With the unfurling of the project, the focus has moved towards a different vision, a sustainable approach based upon the driving principle that new added elements should always be "weaker" and "less resistant" to the original ones (even when the original masonries were made of extremely poor quality stones) and that limited reconstructions are actually necessary for the preservation of the fragile vestiges, an approach implying regular reconstruction/maintenance interventions need to be realised on the site by a technical team, to be financed by the State of Qatar on a long-term basis.

Sustainability in the case of Al Zubarah means three distinct and complementary issues:

1) The development of an administrative and management system capable of guaranteeing the long-term commitment of the State of Qatar and the regular allocation of financial and human resources for the site preservation.

2) The development of national capacities in the fields of archaeology and heritage through capacity-building programmes and the development of new academic institutions and structures.

3) A sustainable approach to technical conservation on the field.

This last point implies that the materials and the techniques used for the preservation of the site are, as far as possible, produced in the region and that local building traditions are integrated in the overall approach to conservation and restoration. Consequently, mostly traditional and/or local materials should be used for the restoration and conservation of Al Zubarah town, while "modern" techniques and materials are generally avoided.

Such an approach has become more and more frequent in architectural and archaeological conservation in the last twenty years. The 1964 Venice Charter, which remains one of the main cultural and intellectual references for the scientific community of conservationists, affirmed that:

"*the conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage (art. 2)*"

and that:

"where traditional techniques prove inadequate, the consolidation of a monument can be *achieved by the use of any modem technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience (art. 10).*"

However, more recent views pay more attention to material contiguity and affinity, and to technological and static compatibility between old and restored elements.

This new sensitivity has lead to the development of a rich technical literature devoted to the rediscovery of traditional constructive know-how and local technical specificities, and to a less dogmatic vision of the necessary distinction between original and restored elements.

The very concept of sacrificial layer and the idea that integrations might be required for the consolidation of the structures (because we want them to continue working according to the static system originally conceived) are the coherent consequence of these new theoretical developments. Such an approach seems particularly meaningful when conservation concerns archaeological sites and ruins, and, possibly, even more so when these ruins are made of particularly fragile or perishable materials. Indeed, the still "fragile" theory developed for the conservation of earthen architecture partially contradicts many assumptions set in the 1960s that were essentially conceived for stone and firebrick structures within the Western World.

Al Zubarah, which is neither a medieval European city nor a classic Roman ruin, and is mostly composed of extremely fragile stones and mortars whose load-bearing and weather-withstanding capacities closely resemble mud brick and adobe structures, provides us with a perfect opportunity to put these contemporary concepts into practice, rather than a mechanical application of the Venice Charter.

If sustainability is the key, and contemporary solutions adopted for earthen architecture and ruins are used as a meaningful technical reference, then the conservation of the city of Al Zubarah should be developed accordingly.

Preserved architectural remains at Al Zubarah (QMA4) in the 1980s

## TECHNICAL PRINCIPLES

The concept presented above is not based upon a theoretical vision detached from reality, but is actually grounded on a detailed analysis of the situation on the field and on the assessment of the characteristics of the building materials and technologies found on site.

At Al Zubarah, substantial parts of the original gypsum-based (anhydrite) mortars and plasters have been preserved, notwithstanding the extremely difficult climatic conditions. While laboratory tests seemed to prove the overall incapacity of anhydrite mortars to resist the prevailing climatic conditions, the visual analysis has forced us to question why laboratory test have proven so negative.

Likely, the laboratory data did not take into consideration the fact that the original local materials present a series of "impurities" that positively influence the capacity of the gypsum to withstand the site conditions. Layers of clay within the rocks, particles of lime, traces of coal, shells and other elements — but possibly also the temperature and the length of the cooking process to obtain the gypsum from the stones — have all produced a relatively high-quality material, based upon traditional knowledge accumulated over time by local masons.

The visual analysis of the masonry seems to confirm that where the building stones and the salt presence could not be improved, the local masons tried to achieve higher resistance with more sophisticated mortars and plasters.

This statement, which needs scientific verification, is one of the starting points for the identification of the "principle" directing the overall conservation of the site. Acknowledging the quality of traditional materials and building techniques, however, does not imply that no modifications are necessary to confront the particularly difficult conditions of the site, leaving room for the scientific research of new solutions.

Research on building materials and laboratory tests can and should continue to provide valuable new information and to control the overall quality of the work implemented on site. Instead

1980s: Exposed town wall

of designing new solutions and materials, however, tests will aim to "reproduce" the original materials and will attempt to identify the technological methods used to produce them.

Similarly, masonry tests will analyse the original tooling and finishing techniques the inhabitants of Al Zubarah used in their houses. They will attempt to reproduce them as accurately as possible to achieve visual, technical, chemical, mechanical and physical homogeneity with the original materials.

At the practical level, it has been agreed that the conservation interventions will be based on lime-based mortars, while new research will be launched to verify the impact of different sands, rocks and cooking techniques in the preparation of the gypsum-based mortars and plasters similar, to those originally used in the city.

The important studies already completed by the technical team on site during Phase 1, and the data produced by the laboratories, coupled with the sustainable approach described above, have allowed us to design very satisfactory lime-based mortars and plasters and to identify the best constructive and tooling techniques to treat the ruined walls of the site. The techniques and building materials to be used in the different areas of the city are presented in detail in the technical fiches of this Conservation Handbook [see Part 3].

In keeping with the principle announced above, the finishing proposed for the restored surfaces is based on the careful analysis of the traditional techniques and on the identification of the different solutions the builders adopted, according to the functions of the buildings.

The exterior plaster of the palace tower, for instance, might share similar chemical/physical data with the internal plasters, but presents a different finishing made with different tools for a different function. The visual analysis of the inner plasters of the rooms next to the date presses — likely used as simple storage areas and not as residential units — shows that the plaster received a much rougher treatment where the traces of the trowel used by the masons has not been erased to achieve a "perfect" result that was not needed by the function.

Excavation work in the 1980s at Al Zubarah (QMA4)

According to the vision outlined above, the conservation of Al Zubarah as an 18th century Gulf city with unique qualities and characteristics is based upon the precise recording and understanding of its technical and architectural elements. From a theoretical point of view, this approach, far from "*falsifying*" the vestiges, actually aims at preserving the ensemble of ruins not only in their material elements but also in their technical, static and almost "*spiritual*" essence.

**TECHNICAL SOLUTIONS**

The original houses and palaces of Al Zubarah were very likely entirely plastered and lime-washed, both internally and externally, and their walls were covered by roofs and terraces protecting them from direct sunlight, rain and wind erosion. The strategic principle to avoid reconstructions and to preserve the site as a ruin implies that no roof is to be created and that the vestiges of the walls remain exposed to the harsh desert and marine environment. In their current state, the masonries are not able to withstand the extreme climatic conditions of the site, and should therefore be protected by a plaster acting as a "*sacrificial layer*" destined to decay and collapse.

The conservation strategy developed by the QIAH heritage team, and validated by the recommendations of the international seminar on the conservation of Al Zubarah held in December 2011, requests that the ensemble of the ruined walls be covered with a layer of plaster. This solution would have a significant visual impact and would radically modify the overall image of the site. The QIAH team and all the workers and supervisors on the site will have to have a clear understanding of the theoretical and technical implications of this "*radical*" choice. It is also essential that any new plaster be applied in a way that is compatible with an archaeological site.

When it is agreed that a protective plaster is to be applied to the original vestiges, we will need to develop a better mix and improved building techniques. The external plaster will be subject to much stronger stresses than the original plaster, which is why we are looking to make use of lime-based mortars and plasters as a coating material. The conservation team has begun to develop a series of lime-based "mixes", taking into consideration not only the purely "scientific" data con-

State of conservation of architectural remains restored in the 1980's in QMA1 (November 2009): Disintegration of building material; collapse of wall structures and cement capping.

cerning their physical and chemical characteristics, but also the availability of the materials, their cost, colour and visual impact on the site. The proposed mortar mixes also have good physical and mechanical qualities and acceptable colour shades.

The team has also designed a set of building techniques to be applied in different areas of the site. The Technical Fiches of the handbook detail these in a clear and simple way. They have defined the "constructive" method to be applied in Al Zubarah, to highlight the difference between the "capping" and the faces of the walls so the site can remain true to its archaeological heritage.

At the practical level, the solution adopted:
• stresses the importance of the overall image of the wall after the conservation is completed;
• achieves an architecturally significant shape for the ruined walls;
• differentiates walls from capping;
• achieves an "irregular" profile for the wall and for the plaster;
• shows the thickness of the plaster with the support of a "sharp" line;
• underlines the difference between the faces and the capping with a different finishing of the plaster;
• reduces the impact of straight corners by "softening" vertical angles with rounded curves;
• avoids covering entirely the last course of stones of the walls with new plaster to favour the visual differentiation between wall and capping.

More research is needed to achieve an even more compatible mix and a more sustainable building material (that does not require the importation of hydraulic lime from Germany), if they are to reproduce an anhydrite mortar similar to the one found in the original plasters of Al Zubarah. In the coming years new solutions, based on the development of high-quality anhydrate mortars and plasters, will be tested and included in upcoming versions of this Conservation Handbook.

Simone Ricca 2012.

Consolidation of 1980s Restoration in QMA2: Taking off cement capping; Consolidation of wall structure, and re-shaping of wall top (2011/2012).

# CONCEPT DEVELOPMENT AND IMPROVEMENT

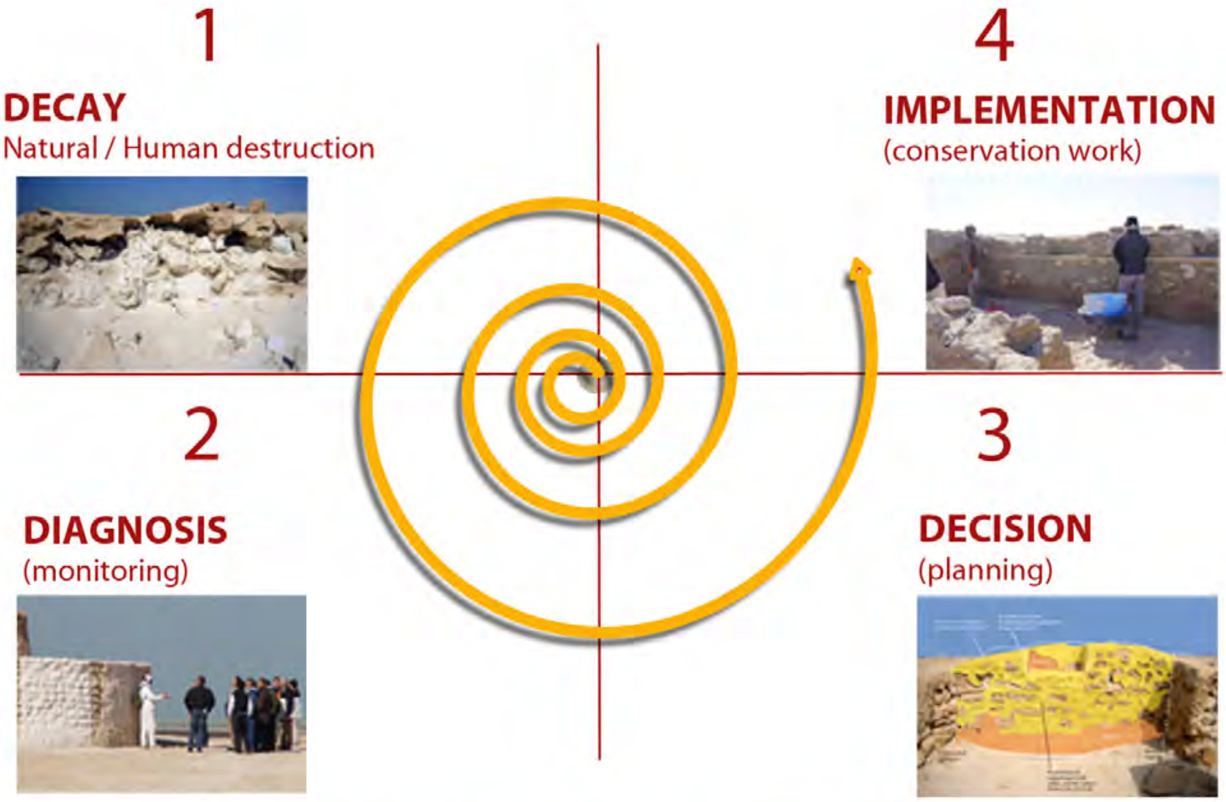
In order to develop a conservation concept, the state of conservation of the exposed architectural remains was documented and analysed. Building materials, e.g. plaster, mortars, and building stones were examined in the lab (see Appendices). On site the decay processes were studied. This diagnosis showed that the predominantly used beachrock has to be covered in order to minimise and reduce decay and disintegration processes, due to the presence of Halite in the beachrock.

The analysis of building materials and soil samples showed also that salts played a major role in the environment. To ensure at least a considerable time frame for conservation and maintenance activities, a sulphate resistant lime (Otterbein NHL) was chosen to execute first works. At the palace (ZUEP04) wall 4010 was covered with a render. The render protects the stone surfaces and preserves the existing situation. No additions were made. Architectural elements were left as they were found and not rebuilt or repaired. Wall face and wall top were executed in the same way and no differentiation was implicated.

This concept works from a technical point of view, to a point, but it does not fulfil our desire to show the remains of an 18th century town and its architecture. Preserving the excavation status makes it, in several instances, impossible to understand the architectural context as well as its character. The indifferent handling of wall surfaces makes it difficult to read the remains as walls with a wall face and a ruined wall top.

An analysis of the 1980's restoration work made it clear that one of the main failures of the works was the non re-plastering of wall faces. The beachrock building stones, as stated before, were of poor quality and were still exposed to the harsh environmental conditions, e.g. strong winds, and were not protected by a layer of plaster, as they were when the houses were built. This resulted in the disintegration of building material components, e.g. gastropods and sand particles, followed by the collapse of wall parts.

Under these conditions, the only suitable solution is to cover the beachrock wall stones with a plaster or mortar. This ensures that the decay process caused by Halite and other minerals is slowed considerably and aeolian erosion is minimised. Although the architectural remains can be described as stone architecture, they show all the decay characteristics of earthen architecture. Taking this into consideration, the re-building of architectural elements using traditional techniques and materials seems to be the only natural course of action, to preserve the architectural remains and to protect the integrity of the town of Al Zubarah. It is hoped that we can reproduce the new plaster surfaces as closely as possible to the historic remains. The continuous monitoring, observation and evaluation of works, damage and decay processes will improve over time, as will our methods, techniques and materials.




THE RESPONSE EVOLVES IN TIME, TO ALWAYS FIT THE CONTEXT BETTER

# CONSERVATION TESTS IN FALL 2009

## 1ST TEST: soil mortar


First mortar tests at Al Zubarah in November 2009: Soil mortar mix with the soil from the site. 1. Wall in QMA2 before test; 2. Close up on wall; 3. Mixing soil mortar; 4. Re-pointing of joints and fill of voids; 5. Fill hole to stone surface; 6. Same situation in December 2010.

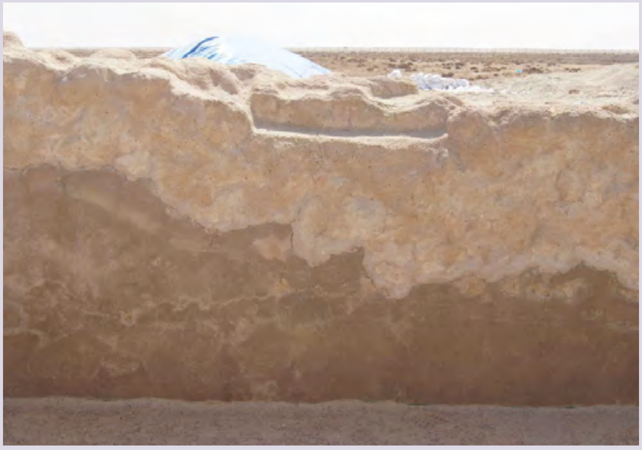
# CONSERVATION WORK in SPRING 2011

## 1ST APPROACH: protective lime slurry

To protect and stabilise the fragile wall structures built with beach rock a lime slurry is applied to the wall. No substantial rebuilding took place only water pockets were filled with smaller stones to eliminate these.

Wall top and wall face were treated the same way. Only a slightly different mortar mix was used. But surface followed the stone shapes as an protective layer. No plaster surfaces were reestablished.

# COMPARISON OF CONCEPTS



**1. Conservation concept (in 2010/2011)**

*"Preserving and Protecting only"*

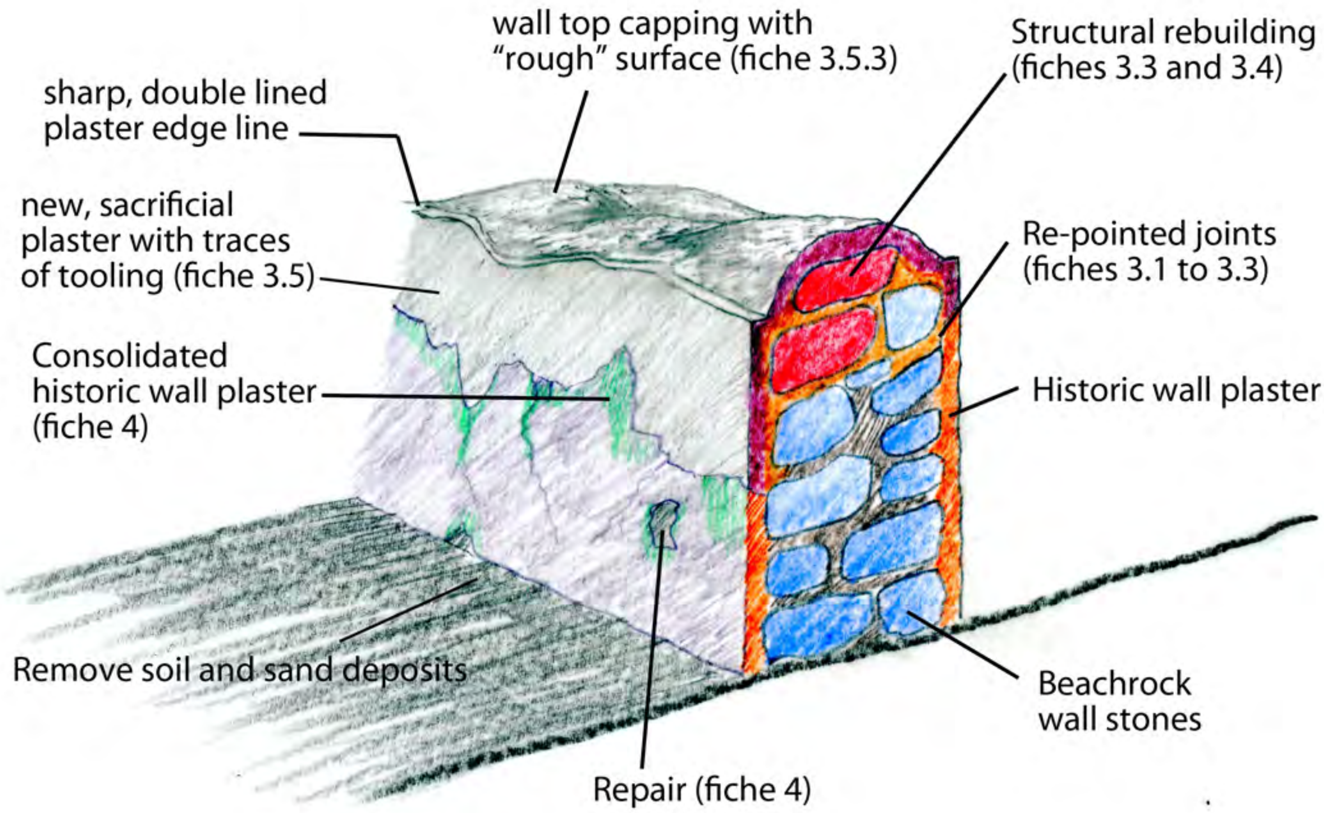
- Lime slurry covering wall stones
- No differentiation between wall face and wall top
- No additions
- No levelling of uneven wall surfaces
- Lime slurry differs in colour and structure to the historic plaster surfaces.
- Based on conservation concepts for stone architecture.

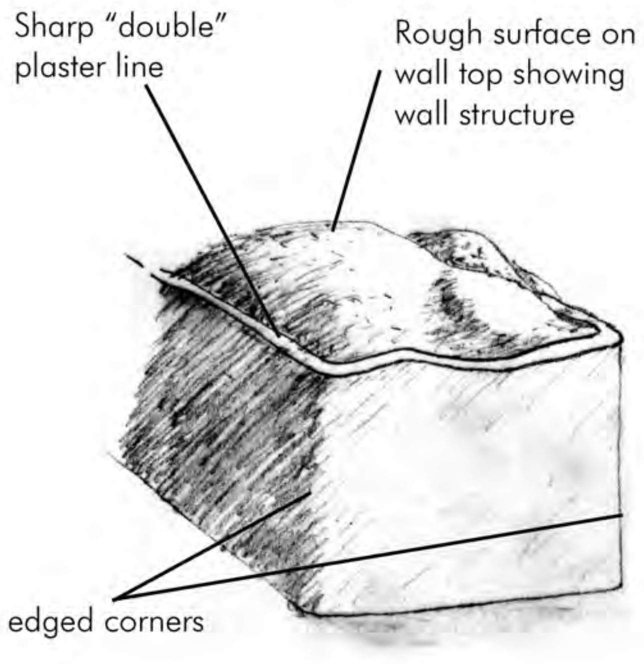
**2. Conservation concept ( since 2011/2012)**

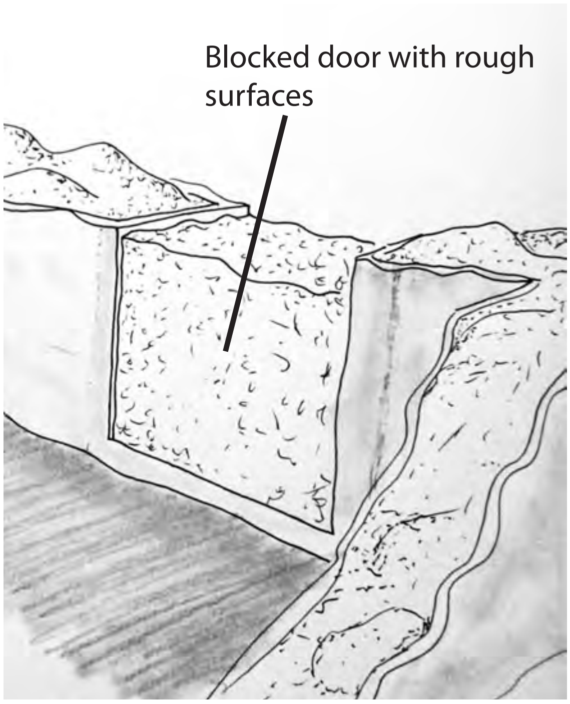
*"Preserving remains, making the architecture understandable"*

- Re-plastering/ Resurfacing of wall faces (to protect building stones)
- Clear differentiation between wall face and wall top with a "double" line stating the wall plaster and a rough wall top surface.
- Surface treatment and appearance of new plaster material (at the moment lime based) close to the historic ones to generate a homogeneous "image".
- Structural rebuilding
- Rebuilding of architectural elements, e.g. wall faces, niches, ledges, and doorways.
- Consolidation of historic plasters: Stabilising surfaces, cementing cracks and border lines, filling of voids and fixing of loose parts. Re-attaching of loose or fallen larger plaster fragments.
- Strategy takes the earthen architecture character of the decay processes into consideration.
- Additions are seen as a sacrificial layer.
- Use of traditional techniques and materials when possible and suitable.

# GENERAL PRINCIPLES AND CONSERVATION CONCEPT



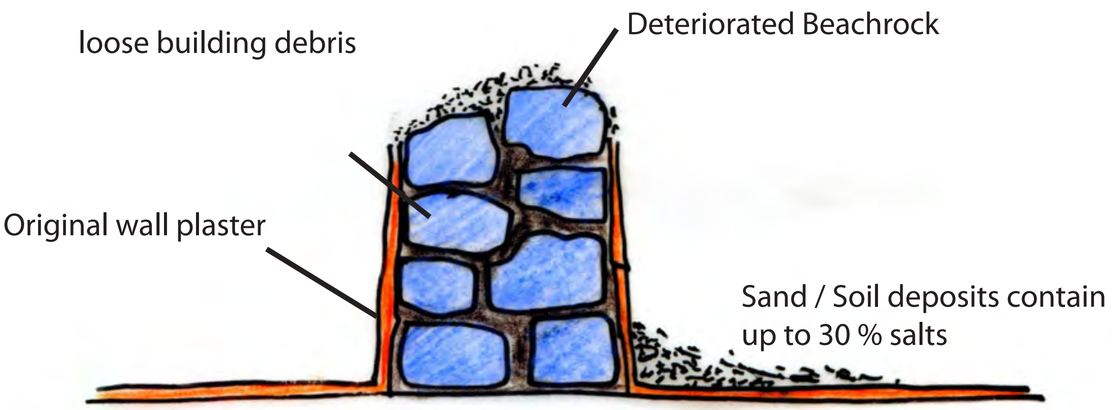



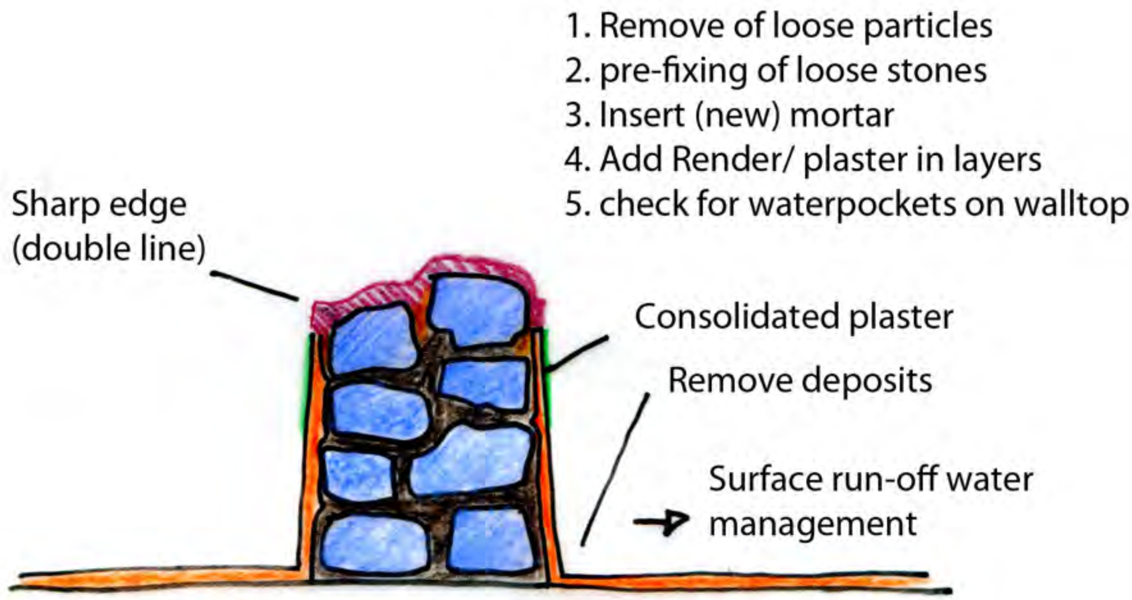



# GENERAL PRINCIPLES

## CHARACTERISTIC SITUATIONS AND PROPOSED SOLUTIONS

SITUATION 1

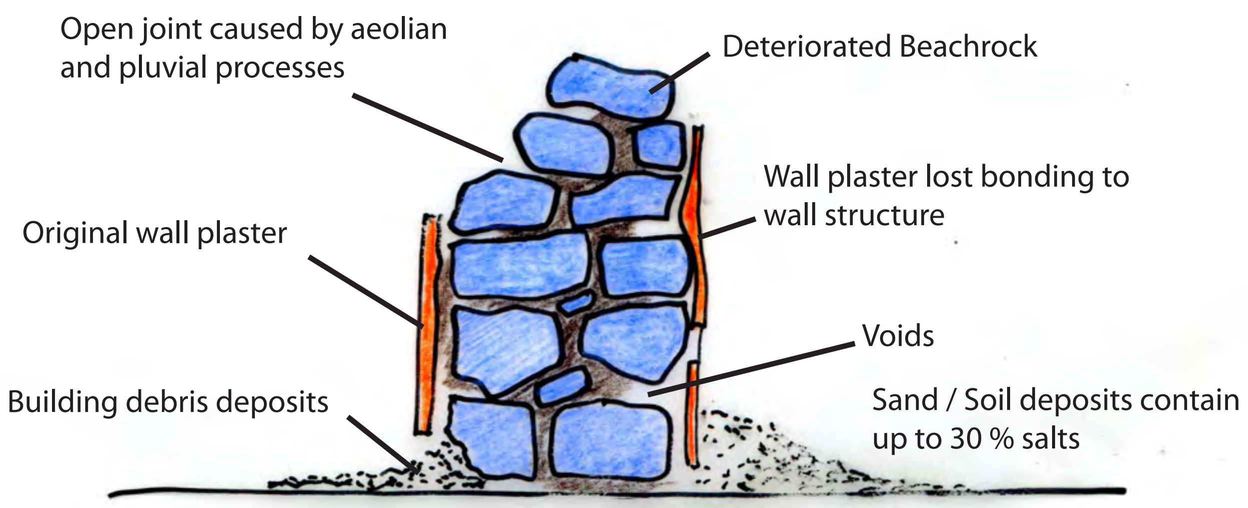


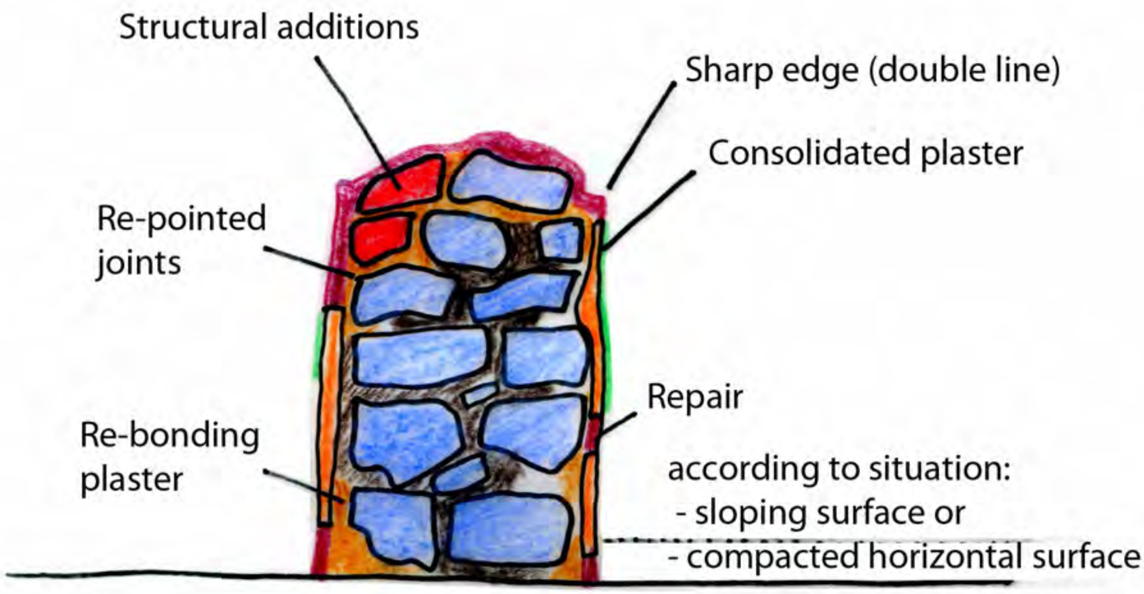
## GENERAL PRINCIPLES

### CHARACTERISTIC SITUATIONS AND PROPOSED SOLUTIONS

SITUATION 2

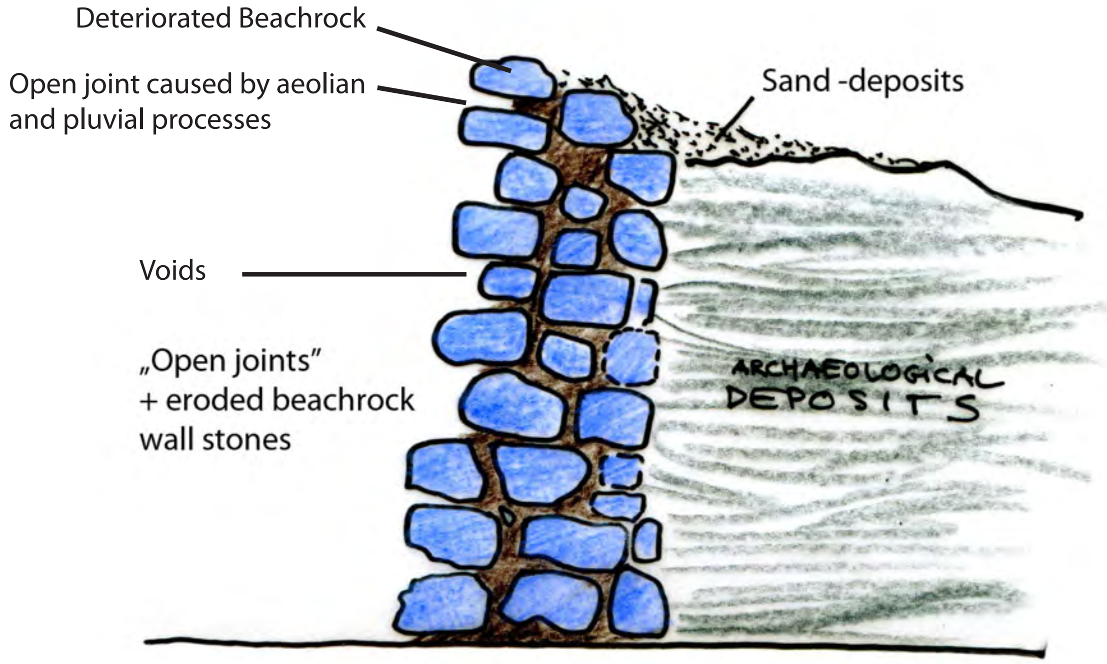



e.g. ZUEP01, Space 102: 604

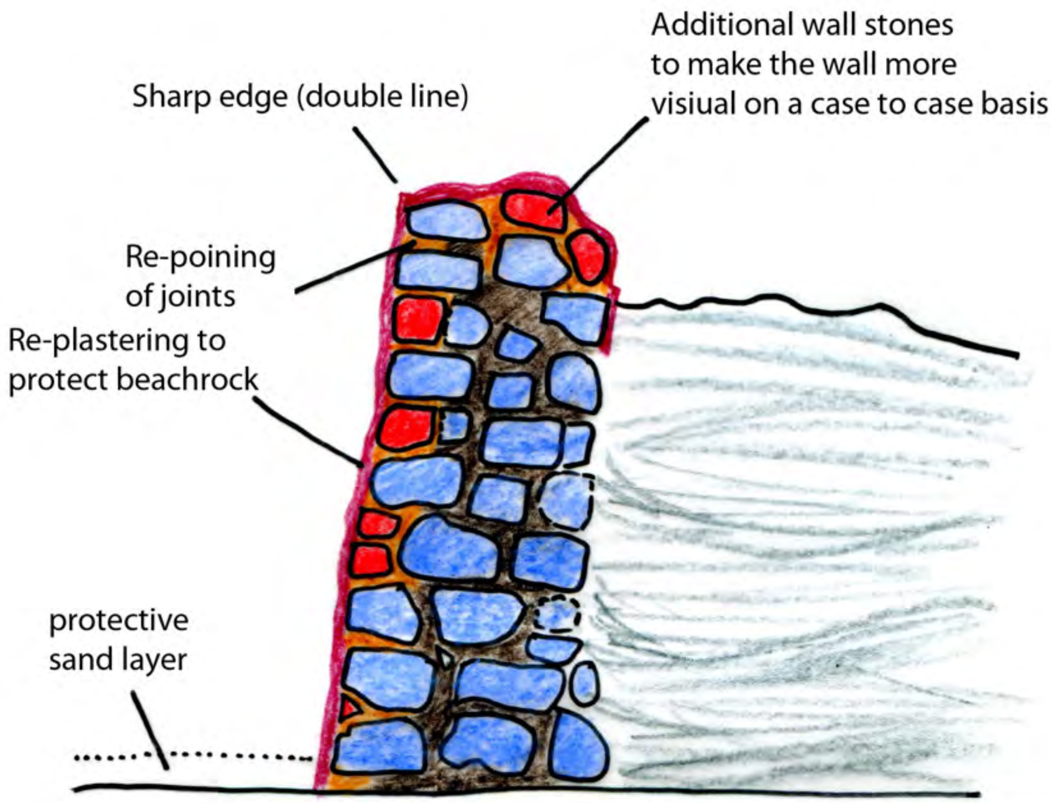


# GENERAL PRINCIPLES
## CHARACTERISTIC SITUATIONS AND PROPOSED SOLUTIONS

SITUATION 3




e.g. ZUEP04, Space 3001: 4010



# GENERAL PRINCIPLES
## AND CONSERVATION CONCEPTS

The following principles were developed for Al Zubarah Archaeological Site, for the conservation of architectural remains:

The conservation work **respects the authenticity** of the archaeological remains and contexts as well as the **integrity of the site** and its features. The urban fabric of Al Zubarah has to be protected to ensure its integrity.

The architecture of Al Zubarah **resembles characteristics of stone and earthen architecture**. This is not only true for its construction but in the nature of its decay.

**No major reconstruction should take place** but structural rebuilding is necessary in several cases to ensure the stability of the wall structures, to protect the soft and fragile wall stones and to maintain the integrity of the overall town plan.

**Plaster surfaces** should resemble historic surfaces in appearance as far as possible.

Three different tooling are attested:
1. rough surface with traces of hand tooling;
2. surface with traces of trowel tooling ;
3. smoother surface with only a few traces of tooling.

The aim is to create a closed, more unified surface instead of accentuating differences. Differences will appear naturally, according to the soils and sand used in the mortar. This reflects the variety of plasters and mortars in the archaeological record. At the moment a hydrated lime produced in Qatar is used as binder, but in future we hope to replace the lime with anhydrite for the plasters. As long as the production of anhydrite is not developed further we will use the Qatari lime, which is performing well.

**Areas not foreseen for presentation will be backfilled permanently**. Temporary backfill of excavation areas will take place when no immediate conservation and consolidation work can be carried out or excavation work is not finished. Backfill should be done properly and should consider surface run-off water management.

**Newly added materials** (plaster and mortar) should be less hard and slightly weaker – or of same strength – than the “original” material.

To protect the fragile vestiges on site only **limited and controlled access** will be given to visitors. Clearly marked and partially raised **walkways** will allow visitors to explore the site but only in the areas open to the public. **Permanent guards** will ensure the rules set out for Al Zubarah Archaeological Site will be followed. To limit the impact of vehicle traffic, one vehicle track for visitors leading to an interim parking zone and one service track for ongoing works on site were established in 2011/2012.

**Regular monitoring** will help us to develop the above mentioned conservation strategies further.

# GENERAL PRINCIPLES
## AND CONSERVATION CONCEPTS
## PLASTER SURFACES AND TOOLING TRACES




QIAH- Tests:
A - very smooth, dense surface, almost no tooling visible
Ba - rough surface with traces of hand tooling
Bb- same as A &B, but with desert sand aggregate
C- washed surface with traces of trowel tooling
D-Archaeological Record: Hand-tooling, tower EP04

# GENERAL PRINCIPLES
## AND CONSERVATION CONCEPTS
## PROPOSED AND USED PLASTERS AND MORTARS

In the conservation of architectural remains at Al Zubarah, several historic and modern mortars and plasters were analysed, tested and optimised to correlate with the historic settings and to withstand the extreme environmental conditions on site (see Appendix 2). These requirements often seem incompatible.
However, the following mortars performed well in fulfilled these requirements:
1. close to historic appearance;
2. use of local materials (when possible);
3. performs well under environmental conditions;
4. same strength and/or slightly softer than original plasters.

Two mixtures were based on locally produced hydrated lime. Two others are based on German Natural Hydraulic Lime Otterbein Hydradur. The cement (which should be tricalciumaluminate (C3A)-free) content is meant to stabilise the mortar before the carbonation process of the lime is finalised. In a mid- to long-term perspective, there is a plan to reproduce anhydrite mortars, as they were widely used at Al Zubarah when it was built.

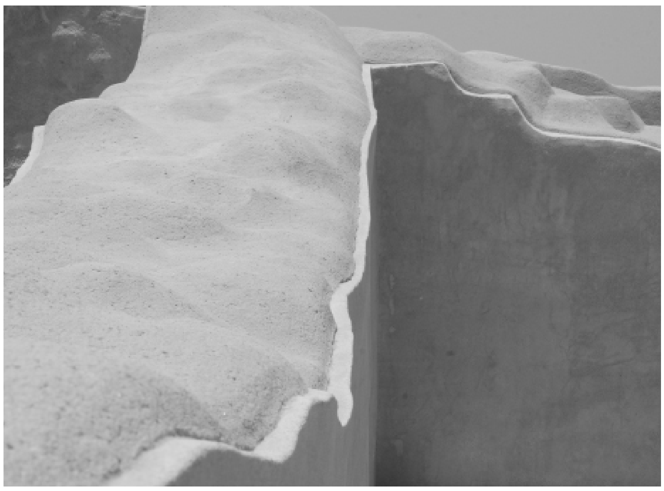
**Wall mortar No. 1.2**
1 part NHL (Otterbein Hydradur) + 3 parts Quartz sand (0-8 mm); Ratio 1:3

**Wall mortar No. 1.51**
2,5 parts Lime (hydrated lime) + 1 part white cement + 12 parts Quartz sand; Ratio 1: 3,4

**Wall plaster No. 1.55**
3,5 parts Lime (hydrated lime) + 1,5 parts cement + 3 parts Quartz sand + 6 parts sieved "Zubarah soil" + 6 parts "desert sand" (reddish in colour); Ratio 1:3.

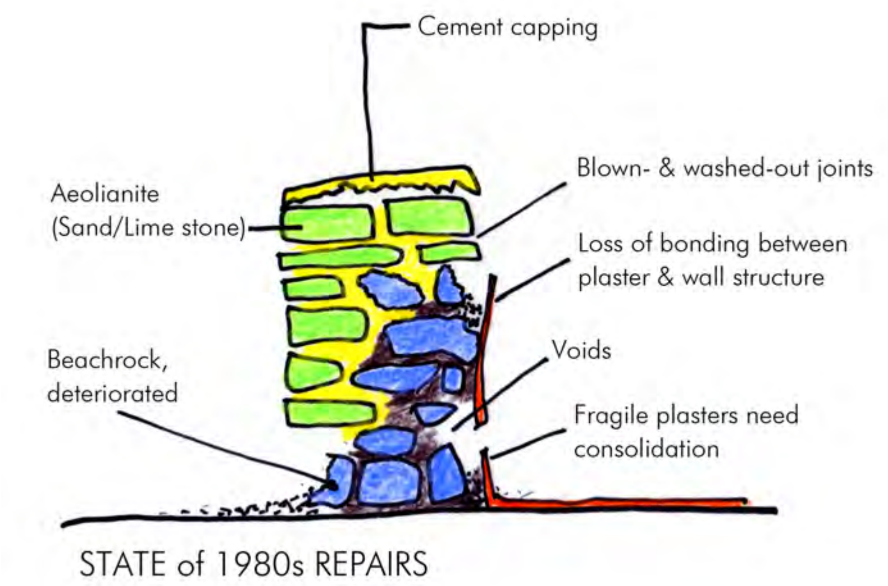
**Wall plaster No. 1.56**
1 part NHL (Otterbein Hydradur) + 1,5 parts "desert" sand + 1,5 parts Quartz sand (0-3 mm); Ratio 1:3

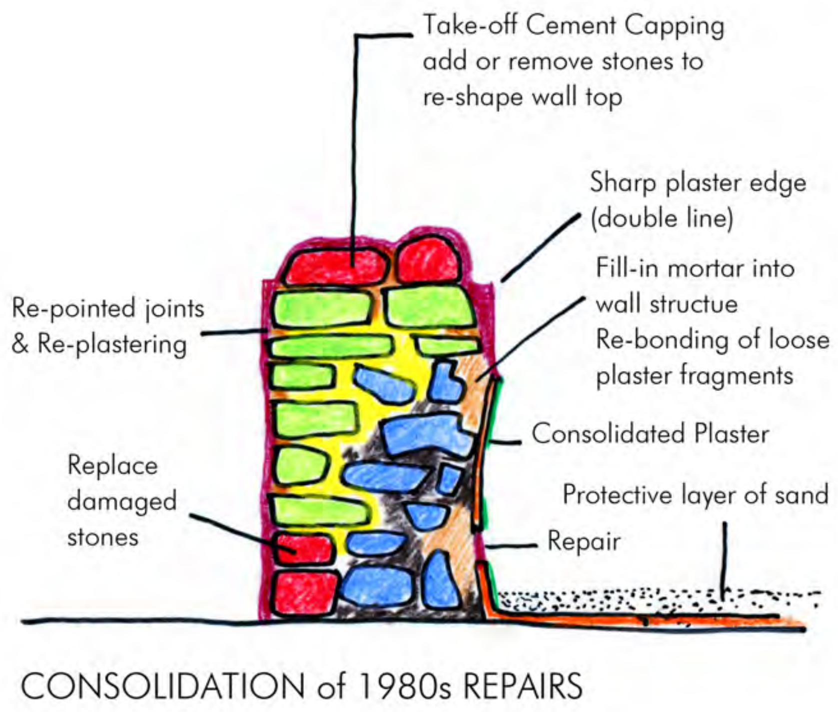
**Note**: NHL should be used in the context with historic (gypsum-based) plasters; hydrated lime in combination with white cement should only be used were no gypsum-based plasters are preserved, due a possible reaction between the tricalciumaluminate (C3A) and the gypsum, which can result in the further disintegration of building materials.



Sharp "double" line defining wall face and wall top (example ZUEP04:4010)

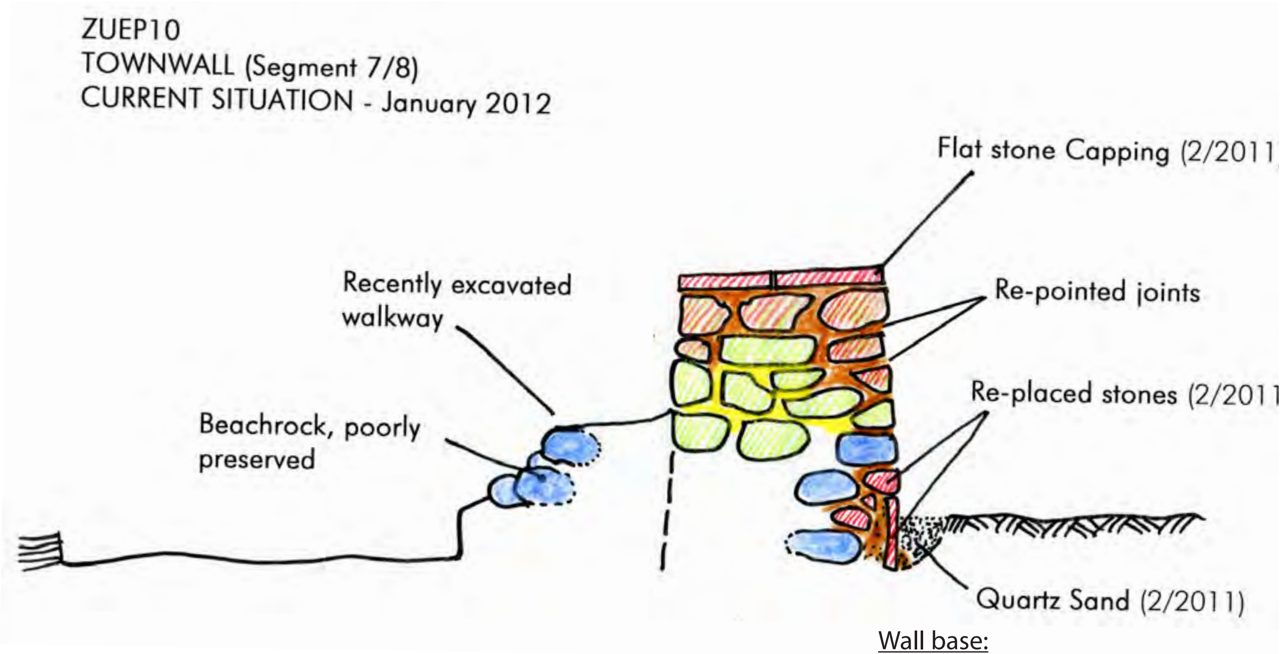
# CONSERVATION CONCEPT FOR EARLIER EXCAVATED AREAS



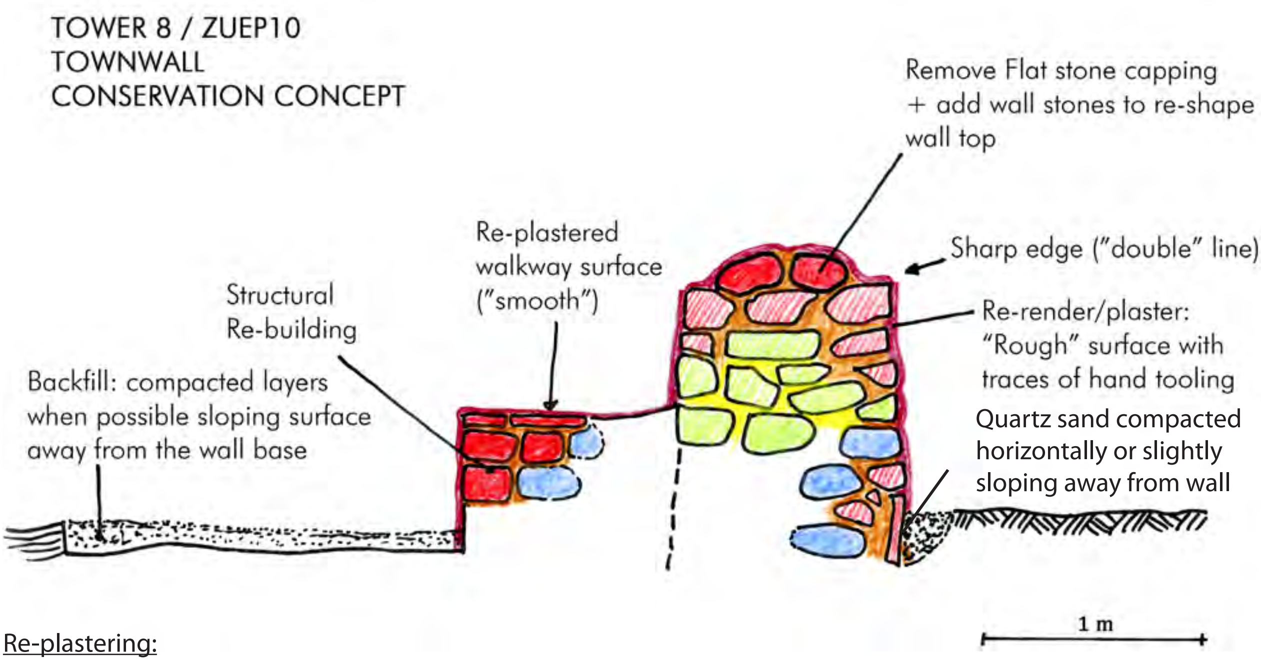

# CONSERVATION CONCEPT:

## TOWN WALL with exposed walkway, e.g. TOWER 8 / EP10



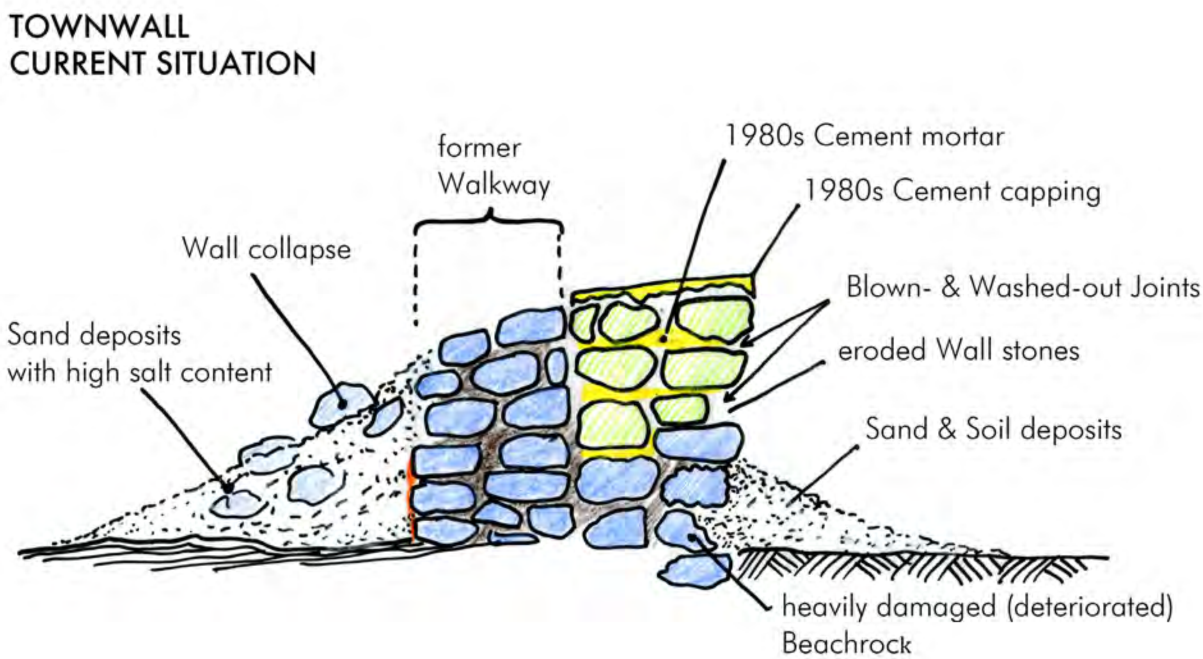

Wall base:
Soft Beachrock is in a poor state; Deterioration & Disintegration of Beachrock components!

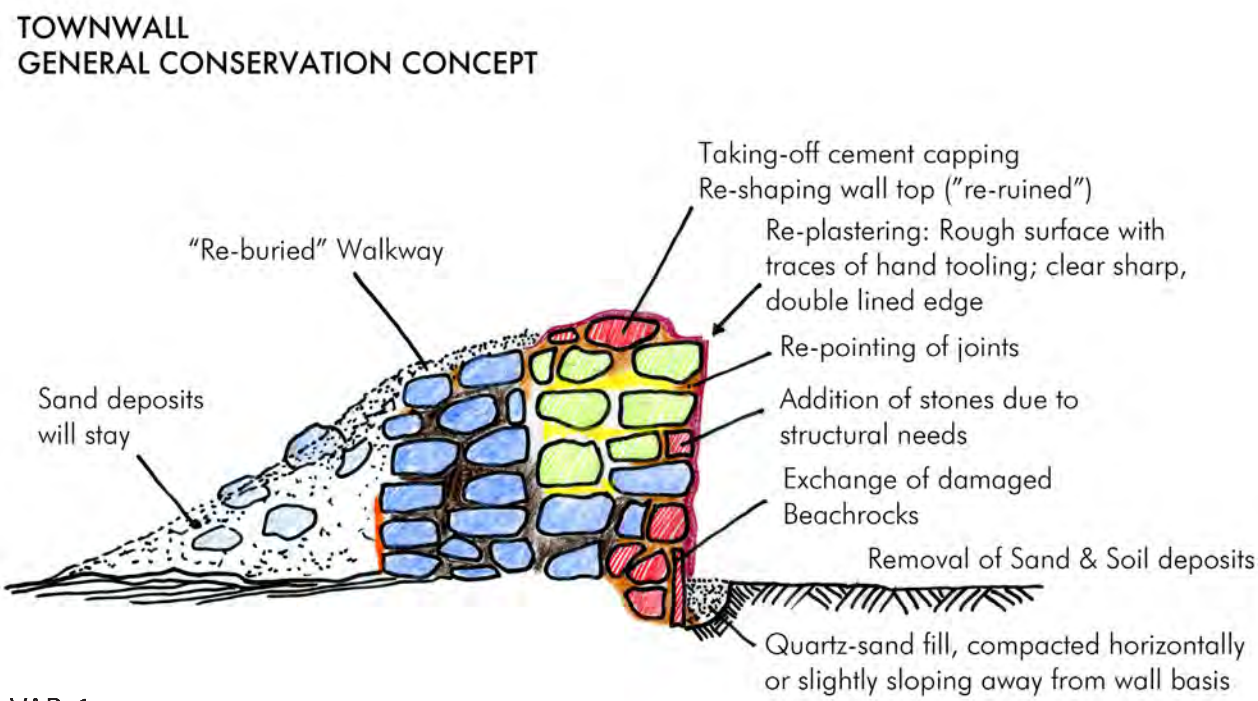
Section of wall segment North of tower 8




Re-plastering:
"Rough" surface with traces of hand tooling; sharp edge (double-line) between wall top and wall face; edged corners

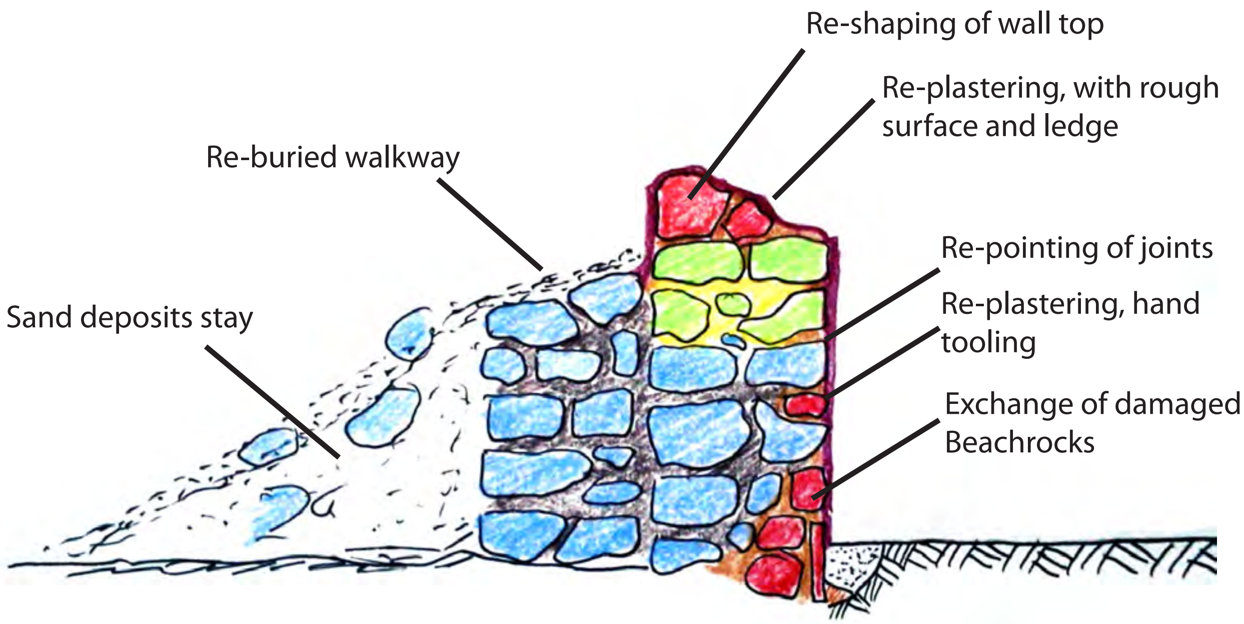
# Conservation Concept: TOWN WALL
for segments exposed in 1980s




VAR. 1

# Conservation Concept: TOWN WALL
for segments exposed in 1980s and by QIAH




VAR. 2

Town wall segment 8/9 with re-shaped crown in March 2012 (VAR. 1).

Town wall segment at tower 4012 (ZUEP04) in March 2012 (VAR. 2).

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
# **NICHES**

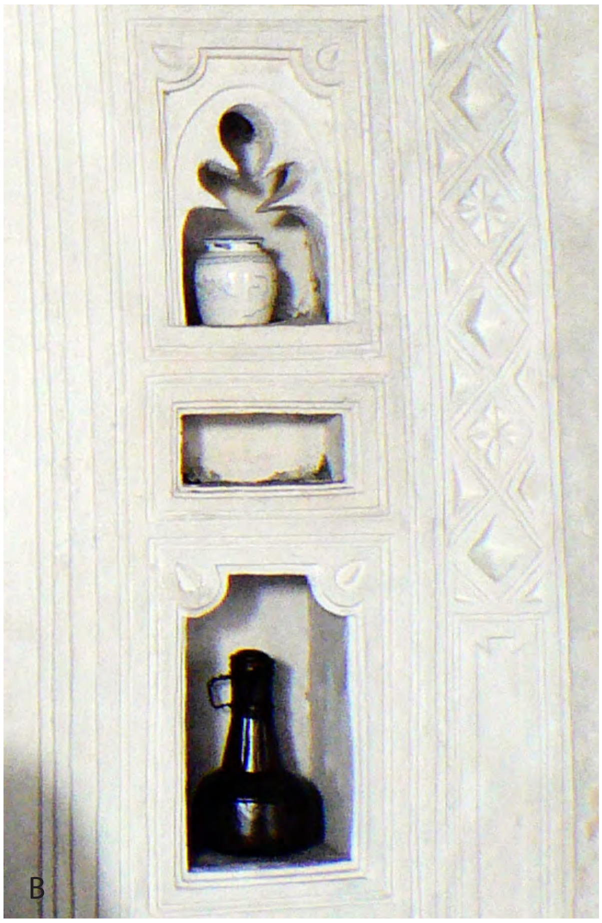
***Niches*** are a common feature throughout Zubarah's architecture. Situated above a plaster panel/ socle, centred, or in regular intervals on the walls. Due to the state of conservation it cannot be stated if some of the niches exposed in the house walls are linked to wind catchers. Some niches seem to have had plaster decorations and decorated frames. Some were obviously arched, but no complete niches have so far been found.

Niches can serve several different functions, such as to:

1. keep things in
2. place a lamp onto it
3. point to *Qibla* direction
4. catch wind and direct it into the building.

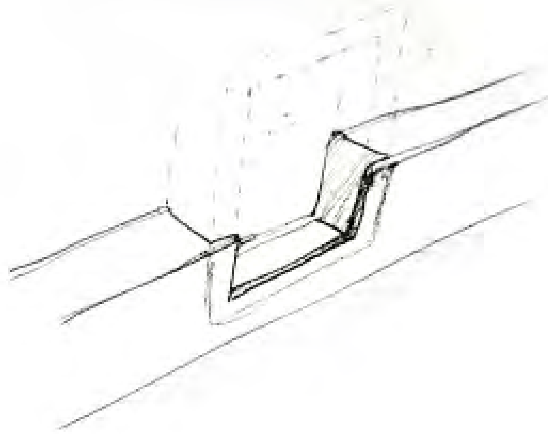
A) Restored example from Saudi Arabia(S. Ricca, 2008)
B) Historic example from Lamu /Somalia (S. Moriset 2009).

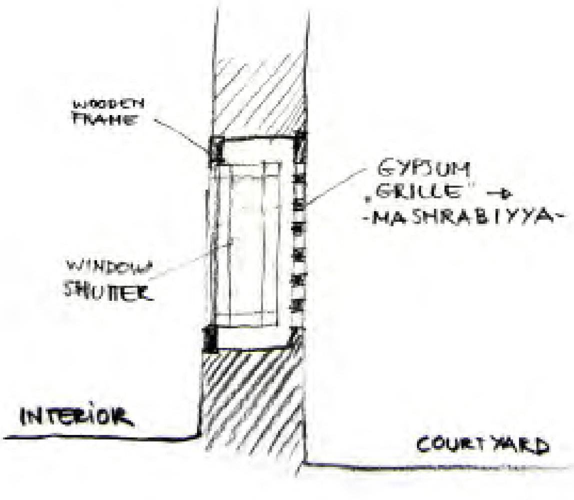
A



B

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
# **WINDOWS**






***Windows*** are a common feature at Al Zubarah. The construction has an elaborated design. In several cases the window has a plaster frame on the exterior encircling a *mashrabiya* – Gypsum grill. In some cases (as shown here), there is a wooden frame on the interior where a shutter would be placed to regulate light and air flow. Often additional wall openings for air circulation were situated above the window. Windows are generally situated close to the floor for people sitting on floor mats.

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
# **DOOR REVEALS**

## BEST PRACTICE GUIDELINES

- AVOID plaster lines on different levels
- AVOID odd arrangements
- AVOID tilted geometry

## DO

- Keep it simple.
- Make the doorway recognisable.
- Stabilise fragile parts.
- Discuss detail on a case-by-case basis.

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
# **CORNERS**

## BEST PRACTICE GUIDELINES



- AVOID plaster lines on different levels
- AVOID odd arrangements and forms.
- AVOID artificial lines
- AVOID  too extreme amplitudes

## DO



- Create logical plaster connections.
- Connect wall faces and plaster lines, where possible.
- Keep levels straight.

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
# **PLASTER LEDGE / PANEL**

## BEST PRACTICE GUIDELINES

Plaster panels and related ledges should be reconstructed where possible and where archaeological evidence is given. The reconstruction of these features will help to show the historic proportions, character and function of the rooms.

If no information is available **NO** reconstructions should take place. For interior plaster surfaces a "smooth" surface treatment with some traces of trowel tooling is recommended to reach a homogeneous image.

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES

## **PLASTER LINE** DEFINING BORDERS BETWEEN WALL FACE AND WALL TOP

## BEST PRACTICE GUIDELINES

AVOID

- plaster lines joining on different levels.
- illogical arrangements and forms.
- artificial lines: do not follow every stone outline with the plaster line: keep it natural
- do not make the line too wide: max. 3 to 4 cm

## DO

- Create logical plaster connections.
- Try to keep levels straight and try to even out height differences.
- Keep the line running naturally.
- Do not follow every single stone outline.
- Keep the width of plaster line between 2 to 4 cm.

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
# **STAIRS**

1

2

The conservation solution for stairs and steps should be planned on a case-by-case basis. Stairs should be completed (Figs. 2 and 3) and stairwell walls should be rebuilt in keeping with the archaeological and architectural context (Figs. 3 and 5). Where a partly destroyed step can be understood as a step (Figs. 1 and 2), only the remains should be consolidated and conserved.

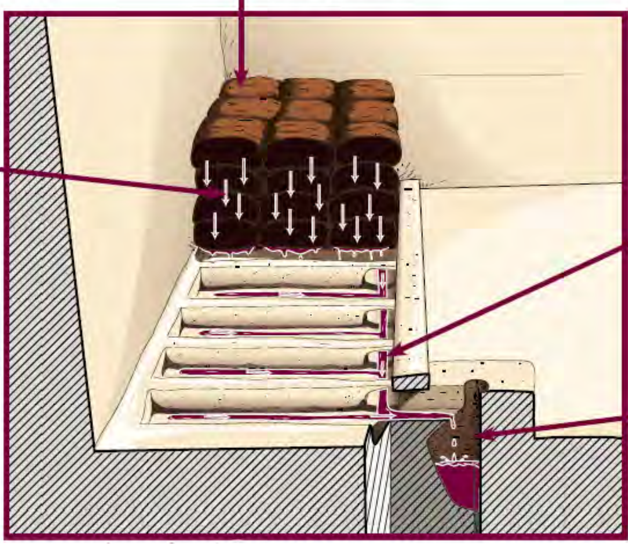
To stabilise, preserve, and consolidate historic plaster in situ, it might be necessary to complete a step or plaster surface (Fig. 4).

3

4

5

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
# **DATE PRESS**




Cut away diagram of a madbassa (date press) excavated at the palace in Al Zubarah (A. Pantos)

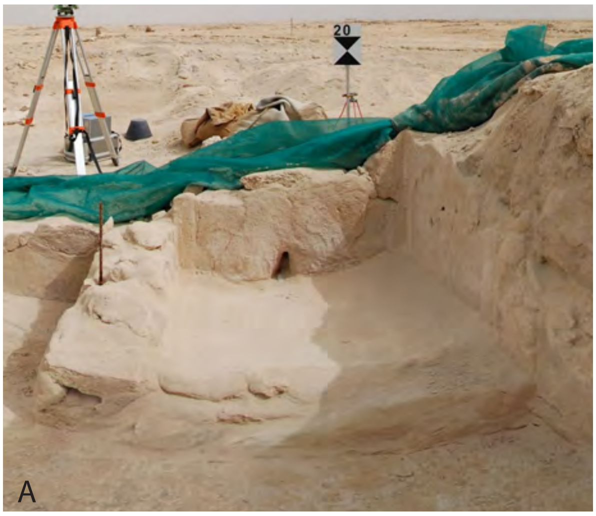
# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
## BENCHES AND PLATFORMS

Surfaces of benches or platforms should be done with a smooth surface and a sharp plaster edge. NO double line! e.g. platforms in the Palace (ZUEP04). Same is true for benches, e.g. the reconstructed benches in QMA2.

Platform in EP04 (2012 consolidation)

Bench in QMA2 (1980s reconstruction)

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
## HAMMAM INSTALLATIONS


A


B


C


D

***Hammams*** are common features throughout the settlement. Raised 10 to 30 cm above the floor level the platform shows a very smooth plaster surface. The Hammam installation drains through a sewer into an external, underground-placed sewage tank. Some hamams are showing elaborated plaster decorations (e.g. in ZUEP01 [A]), others are kept very basic and simple (e.g. in ZUEP04 [B to D]).

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
## FLOORS

Historic (anhydrite) plaster floor at the palace; (03/2010).

Pavement made of conglomerate stone slabs; This kind of pavement can also be found under the plaster floors as an underbed (03/2010).

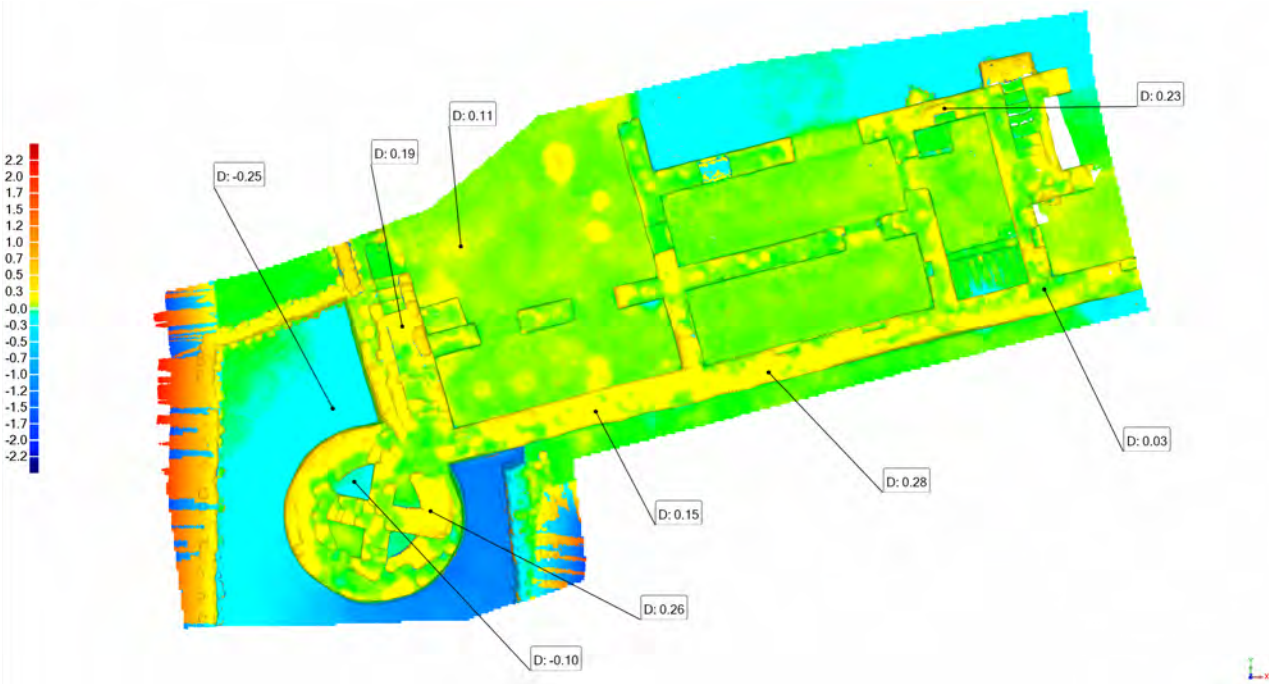
Cleaned floors should be covered by mesh or geotextile before a layer of fine sieved soil or better quartzsand is placed on. The layer of sand sould be around 5 cm.

# CONSERVATION CONCEPT FOR ARCHITECTURAL FEATURES
## BACKFILL AND PROTECTION OF SECTIONS & WALLS

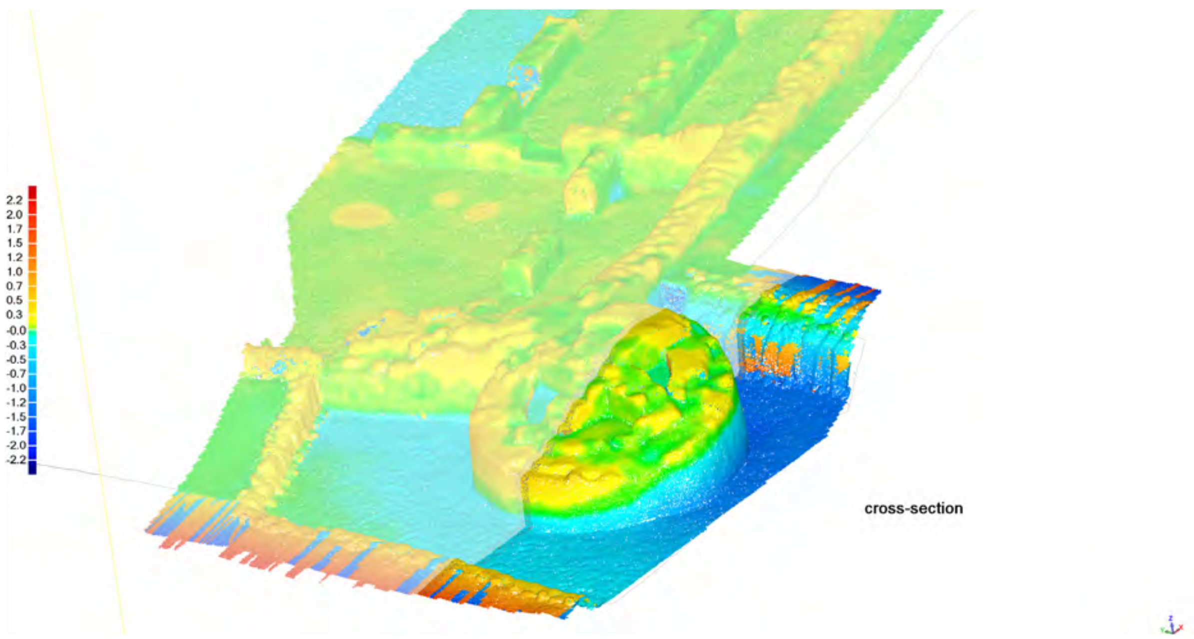

Backfilling features and trenches


Protection of excavation trench sections

# MONITORING STATE OF CONSERVATION
## USING 3D-LASER SCANNING







## MONITORING STATE OF CONSERVATION
## USING 3D-LASER SCANNING

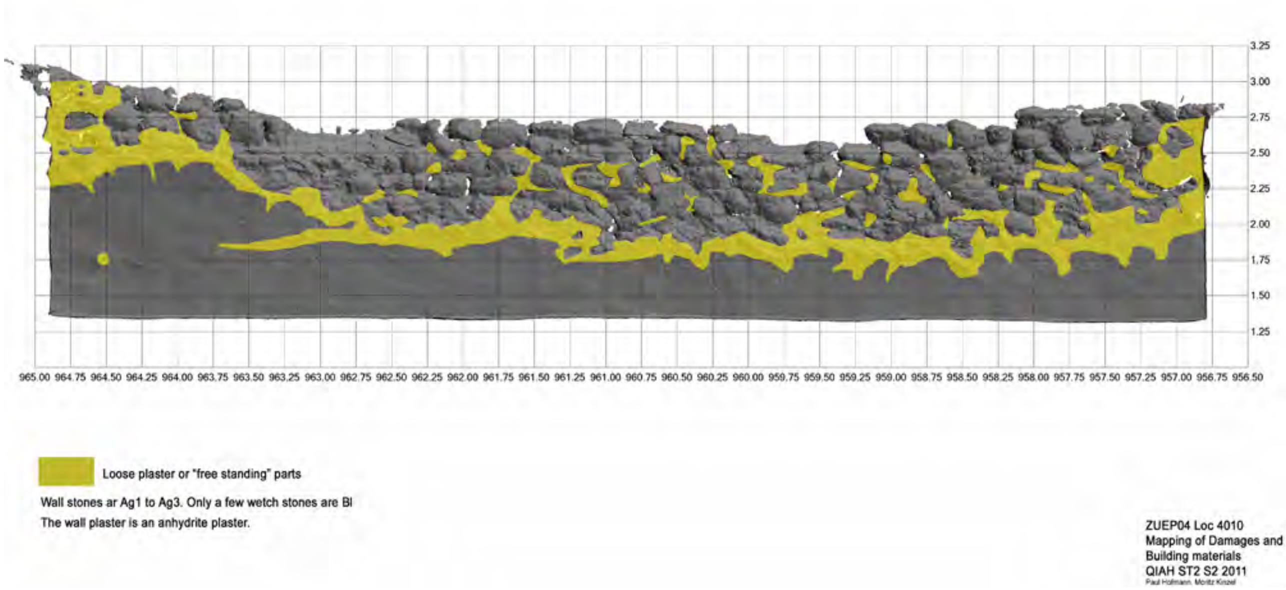
In addition to the traditional inventory and photographic record, 3D laser scanning provides fantastic possibilities for monitoring changes and decay patterns over time. Comparing scans by overlays allows us to visualise consolidation measures, e.g. structural rebuilding, but also the decay of building materials as well as the effectiveness of conservation measures. The study and analysis of this documentation will allow us to develop maintenance cycles and to revise the conservation materials and techniques we apply.

In contrast to traditional recording techniques, 3D laser scans allow us to look at the recorded structures in 3D, not simply as two dimensional images or a plan. Defects caused by weathering, thermal expansion and salt crystallisation can be followed and documented in great detail to provide additional information on the environmental conditions at Al Zubarah Archaeological Site.

## MONITORING STATE OF CONSERVATION
## MAPPING OF DEFECTS

Defects, deterioration patterns and weathering of materials should be mapped and recorded before conservation and consolidation measures take place to help define the methods and materials we use as well as allowing us to discuss the extent of the measures that are needed. The recording should be executed by an expert or skilled person (restorer, conservator, craftsperson). It can be done on hand drawings, photoplans and/or plan generated out of scan point clouds.

Defects and the state of conservation in general should be documented at least with photographs (with and without scale) before, during and after a conservation measure has taken place. The documentation has to be added and linked to the Inventory database (conservation log) as soon as possible to make sure that no data is lost. The mapping of defects and deterioration patterns helps us to identify patterns over time, to define conservation methods and materials and to define the necessary workforce required to preserve the remains.



# CONSERVATION MANUAL (PART 3) OVERVIEW: WHERE TO APPLY WHICH *FICHE TECHNIQUE*

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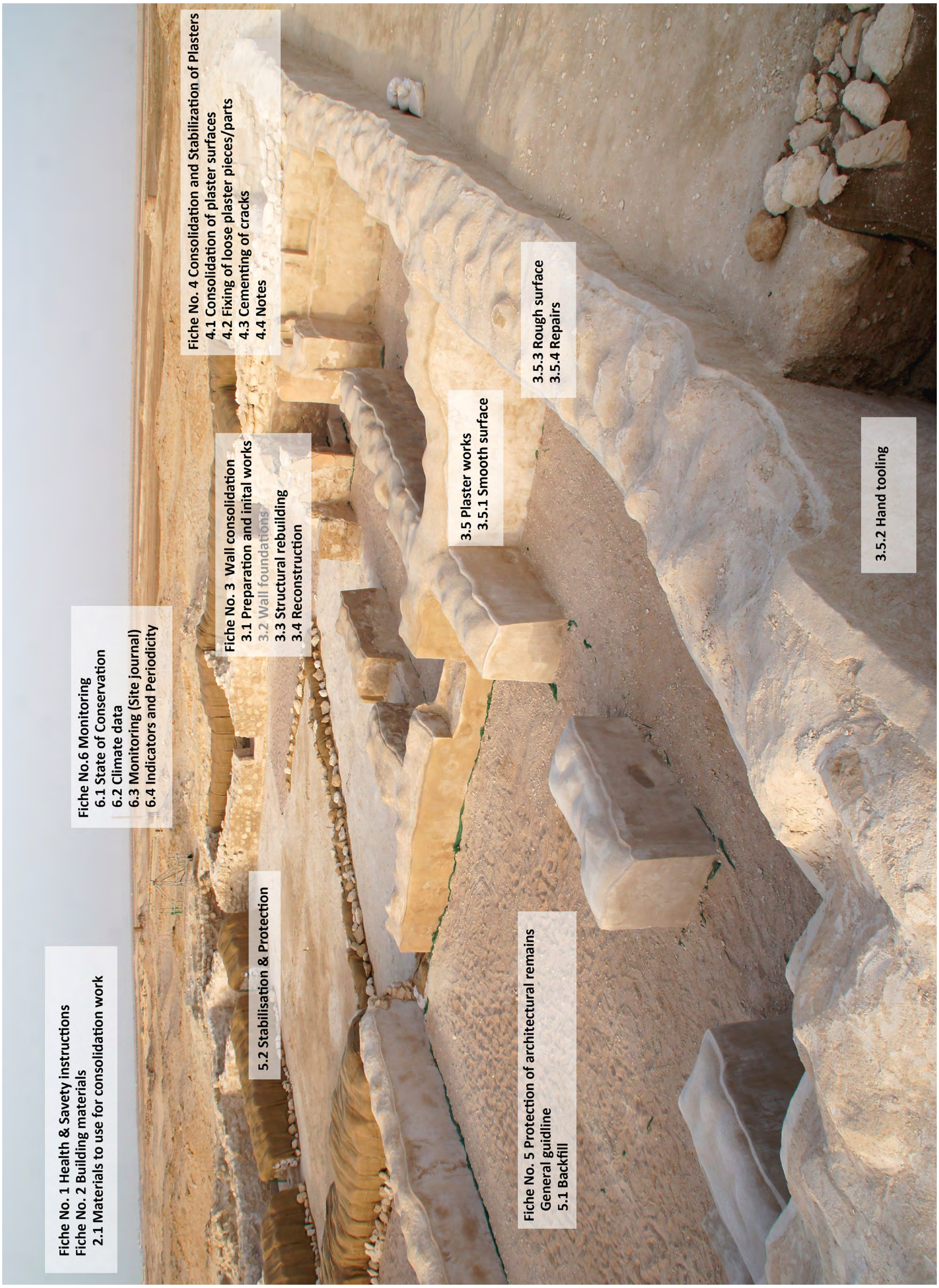


PART 3

# CONSERVATION MANUAL

## FICHE TECHNIQUE

## INSTRUCTIONS

3

QATAR ISLAMIC ARCHAEOLOGY AND HERITAGE PROJECT

مشروع قطر لعلم الآثار و التراث الإسلامي

Heritage | Archaeology | History | Environment

# LIST OF FICHES



**Conservation Handbook for Al Zubarah Archaeological Site - PART 3**
Edited by Moritz Kinzel with contributions by Simone Ricca, Paul Hofmann and Robert Sobott.
First Edition January 2013 QIAH-01-02-HE-1000 DOHA /COPENHAGEN 2013
ISBN 978-87-89221-08-3
Carsten Niebuhr Centre for Multicultural Heritage - Materiality in Islamic Research Initiative
Department of Cross-Cultural and Regional Studies - ToRS
University of Copenhagen and the Qatar Museums Authority - Al Zubarah Archaeological Site.

FICHE No.1

# HEALTH & SAFETY INSTRUCTIONS
## FOR AL ZUBARAH ARCHAEOLOGICAL SITE

**Field of application: general**
**AMBULANCE (Police & Fire) dial 999**

## Personal Security

- Wear security boots.
- Always wear gloves and glasses when you are working with lime and stones, to avoid injuries (see Fig. 1).
- Wear appropriate clothing.

In order to protect yourself against the harsh climate:

- Drink plenty of water throughout the day (Fig.2),
- wear sun-cream with a high UV filter (Fig.3).

1

2

3

FICHE No.1

# HEALTH & SAFETY INSTRUCTIONS
## FOR AL ZUBARAH ARCHAEOLOGICAL SITE

**Field of application: general**
**AMBULANCE (Police & Fire) dial 999**

## PROTECTION OF BUILDING MATERIALS

Make sure that you have

1. a secure storage and mixing areas; clear and well organised (see figure at the bottom),

2. separated the materials,

3. placed the water tanks on secure platforms to avoid cracks in the bottom.

Materials (especially Lime, Gypsum and Sand) should be covered with fabric to avoid direct sunlight. (pictures on the right: Sand bags covered with plastic fabric and builidng materials stored in house).

**FICHE No.1**

# HEALTH & SAFETY INSTRUCTIONS
## FOR AL ZUBARAH ARCHAEOLOGICAL SITE

**Field of application: general**
**AMBULANCE (Police & Fire) dial 999**

## PROTECTION OF ARCHAEOLOGICAL REMAINS


Adjunctioned building elements should be protected, e.g. Floors, Doorways, etc. to avoid damages during the work process.

**Building up protective layers:** protective fabric, e.g. Mesh (Fig.1), 5 cm Sand layer (Fig.2) for walkway planks have to be added accordingly (Fig.3 & 6). In addition doorways, thresholds, recesses etc. have to be protected separately (Fig. 4 -6).





**FICHE No.1**

# HEALTH & SAFETY INSTRUCTIONS
## FOR AL ZUBARAH ARCHAEOLOGICAL SITE

**Field of application: general**
**AMBULANCE (Police & Fire) dial 999**

## SAFE & SECURE HANDLING OF TOOLS

Safe and secure handling of power tools:
1. clear cable routing
2. clear power distribution
3. Read instructions for Mixers, Drills, Hoovers, Compressors, Generators, etc. prior to their use in field.

Tools and vehicles should be treated gently.
DO NOT risk damages or losses.

Stay with vehicles on the marked tracks (ask for the latest update of the track map distributed by the site manager).
DO NOT drive, never ever, into the Sabkha!
AVOID crossing archaeological features as much as possible!
Be aware of archaeological features outside the town wall of Zubarah (e.g. cementery, screening walls and saline areas)!

## How to deal with archaeological finds and architectural remains in general?

When you find archaeological objects please contact an archaeologist and/or your project coordinator.
Do not move or touch finds!
Take a photograph and ask for advice.....(see telephone list at ZRS)

FICHE No.2.1

# BUILDING MATERIALS
## TO USE AT AL ZUBARAH

**Field of application: general**

**STONE MATERIAL**

for Replacements, structural rebuilding and reconstructions:

KA, LA, BL, LO, AG3 according to Appendix 1 classification of building stones

**BINDER**

Natural hydraulic Lime (hL)

White cement (wC)

Hydrated lime (wLh)

**ADDITIVES**

Quartz sand 0-10; sieved on the spot to ca. 0-4

"Zubarah" Soil, sieved on the spot to ca. 0-4

"Desert" sand, ca. 0-2

Desert sand (ds)

Quartz sand 0-10 (qs10)

Quartz sand, sieved to 0-2 (qs2)

Soil from Zubarah, sieved to 0-2 (so2)

Mischungen:

| No | hl | wC | wLh | ds | qs10 | qs2 | so2 | Mix | using | fiche |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.2 | 1 | | | | 3 | | | 1:3 | Consolidation, rebuilding, reconstruction, joints, base for 1.55 | 3.2<br>3.3<br>3.4 |
| 1.51 | | 1 | 2,5 | | 12 | | | 1:3,4 | Consolidation, rebuilding, reconstruction, joints, base for 1.56 | 3.2<br>3.3<br>3.4 |
| 1.55 | | 1,5 | 3,5 | 6 | | 3 | 6 | 1:3 | Plaster, based on 1.51 | 3.5 |
| 1.56 | 1 | | | 1,5 | | 1,5 | | 1:3 | Plaster, based on 1.2 | 3.5 |

FICHE No.2.1

# BUILDING MATERIALS
## TO USE AT AL ZUBARAH

In the conservation of architectural remains at Al Zubarah, several historic and modern mortars and plasters were analysed, tested and optimised to correlate with the historic set-tings and to withstand the extreme environmental conditions on site. These requirements often seem incompatible.

However, the following mortars performed well in fulfilled these requirements:

1. close to historic appearance;
2. use of local materials (when possible);
3. performs well under environmental conditions;
4. same strength and/or slightly softer than original plasters.

Two mixtures were based on locally produced hydrated lime. Two others are based on German Natural Hydraulic Lime Otterbein Hydradur. The cement (which should be tricalciumaluminate (C3A)-free) content is meant to stabilise the mortar before the carbonation process of the lime is finalised. In a mid- to long-term perspective, there is a plan to reproduce anhydrite mortars, as they were widely used at Al Zubarah when it was built.

**Wall mortar No. 1.2**
1 part NHL (Otterbein Hydradur) + 3 parts Quartz sand (0-8 mm); Ratio 1:3

**Wall mortar No. 1.51**
2,5 parts Lime (hydrated lime) + 1 part white cement + 12 parts Quartz sand; Ratio 1: 3,4

**Wall plaster No. 1.55**
3,5 parts Lime (hydrated lime) + 1,5 parts cement + 3 parts Quartz sand + 6 parts sieved "Zubarah soil" + 6 parts "desert sand" (reddish in colour); Ratio 1:3.

**Wall plaster No. 1.56**
1 part NHL (Otterbein Hydradur) + 1,5 parts "desert" sand + 1,5 parts Quartz sand (0-3 mm); Ratio 1:4

**Note**: NHL should be used in the context with historic (gypsum-based) plasters; hydrated lime in combination with white cement should only be used were no gypsum-based plasters are preserved, due a possible reaction between the tricalciumaluminate (C3A) and the gypsum, which can result in the further disintegration of building materials.

Hydrated lime produced by the QNCC

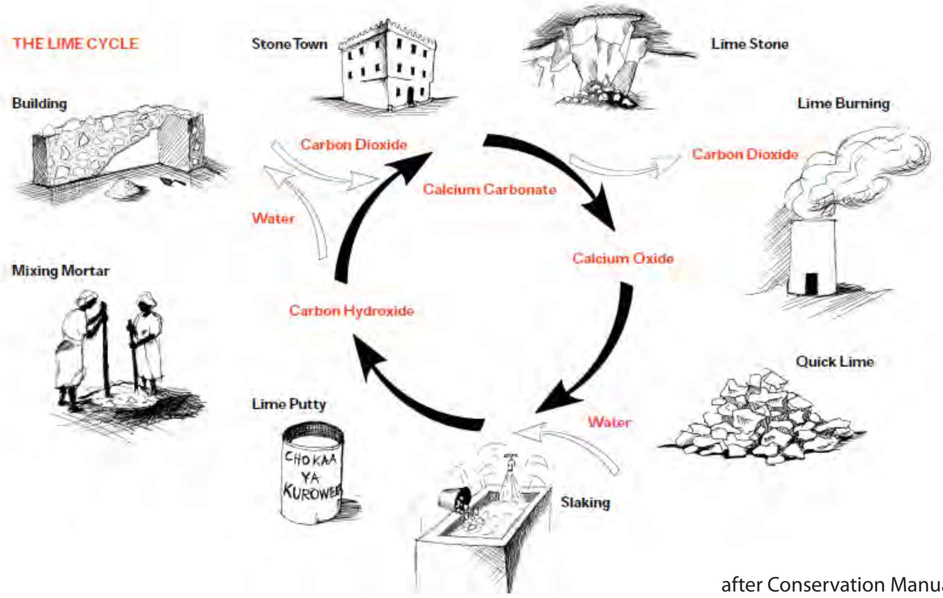
Natural Hydraulic Lime (NHL 5) produced by Otterbein

Gypsum produced by Qatari Saudi Gypsum

FICHE No.2.2

# BUILDING MATERIALS
## AT AL ZUBARAH

LIME




after Conservation Manual for Zanzibar

ANHYDRITE

| Mineral | Formula | Lime (CaO) | Sulfur Trioxide ($SO_3$) | Water of Crystallization ($H_2O$) |
|---|---|---|---|---|
| Gypsum | $CaSO_4 \bullet 2H_2O$ | 32.6 | 46.5 | 20.9 |
| Anhydrite | $CaSO_4$ | 41.2 | 58.8 | 0.0 |

### Mineralogy

Gypsum forms monoclinic crystals with a perfect {010} cleavage and distinct cleavages along {100} and {101}. It is distinguishable from anhydrite by its lower Mohs hardness (2.0 versus 3.5) and specific gravity (2.24 versus. 2.97 g/cm2). Pure gypsum is colorless, but may be tinted yellow, red, and brown because of the presence of impurities. Twinning is common along {100}, forming "swallowtail twins." Gypsum is relatively soluble in fresh water (about 0.2 g/100 g H2O) and is easily dissolved or eroded in conditions of high humidity or rainfall. Anhydrite forms orthorhombic crystals with perfect cleavages along {100} and {010} and a good cleavage along {001}. Anhydrite has a Mohs hardness of 3.5 and a specific gravity of 2.97 g/cm2. Pure anhydrite is colorless, but the color is variable from colorless to dark gray (Sharpe & Cork 2006:519-540).

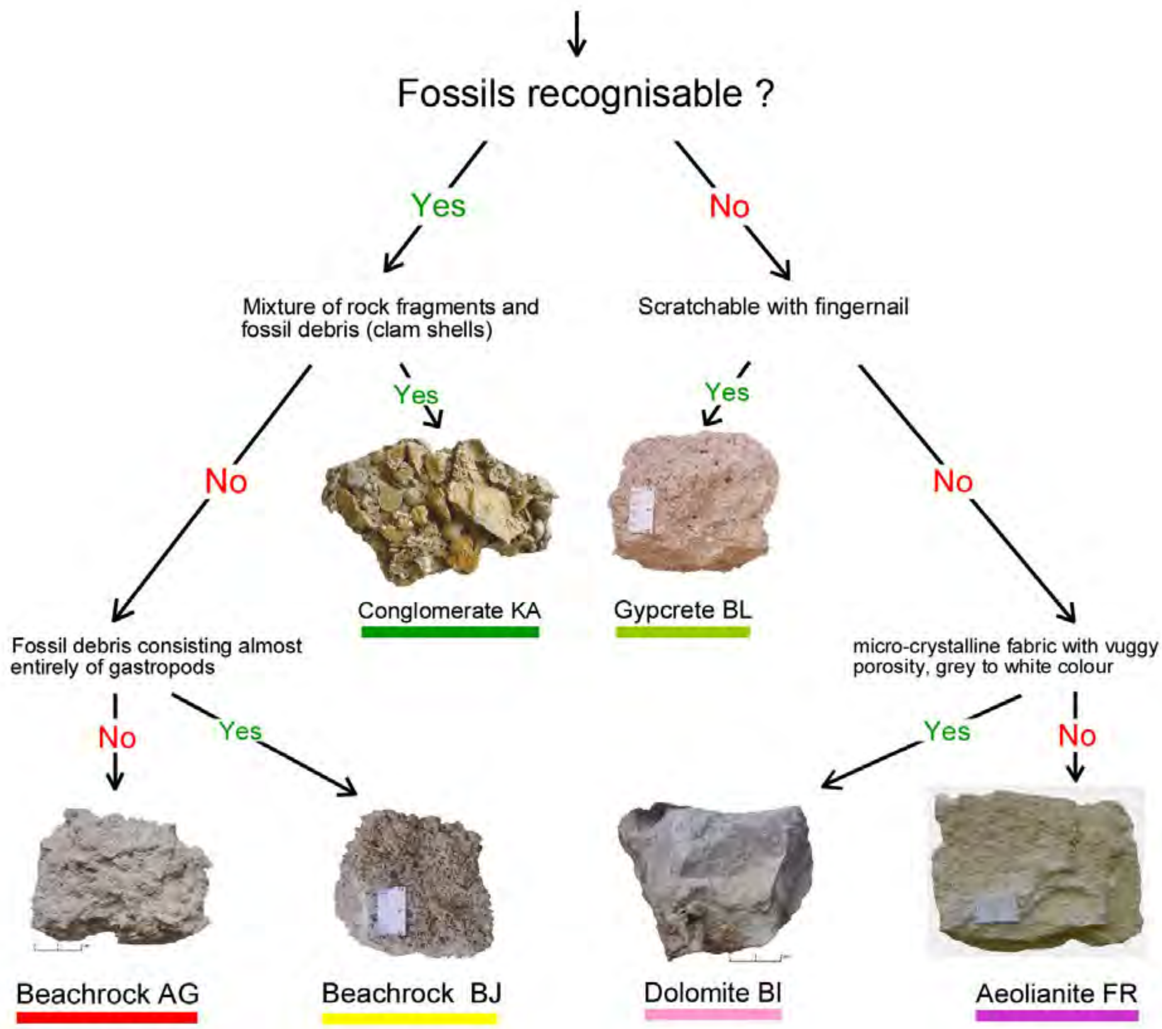
### Sabkha Evaporites

Sabkha is an Arabic term referring to a coastal tidal flat. Numerous geological studies in the 1960 and 1970s examined the formation of gypsum and anhydrite minerals along the Trucial Coast region of the Persian Gulf (e.g., Kinsman 1966, 1969; Butler 1970). These deposits are characterized by a distinctive suite of sediments, including lagoonal limestone, intertidal algal mat limestone and nodular gypsum, and anhydrite-bearing, fine-grained terrigenous or calcareous sediments. Gypsum and anhydrite form by precipitation of supersaturated brine in the pore space of the tidal-flat sediments. Nodular gypsum and anhydrite are the most common forms, but large poikilitic selenite crystals may also form (Sharpe & Cork 2006).

FICHE No.2.2

# BUILDING MATERIALS
## AT AL ZUBARAH

**IDENTIFICATION SCHEME FOR BUILDING STONES** ATTESTED AT AL ZUBARAH



FICHE No.3

# CONSOLIDATION OF WALLS
## AT AL ZUBARAH TOWN

**Field of Application: general**
**PERSONNEL:** Skilled craftsperson with trained workforce
**TOOLS:** Brushes, Industrial hoover, spatulae, trowel, bucket, sponge, water pump, mason hammer,etc.
**MATERIALS:** Water, Otterbein NHL5, Quartz sand
Fiches: 3; 3.1; 3.2; 3.3; 3.4; 3.5 (3.5.1, 3.5.2, 3.5.3, 3.5.4)


Tower (4012) at palace before consolidation (2011)


Tower (4012) at palace after consolidation (2012)


Window at palace before consolidation (01/2012)

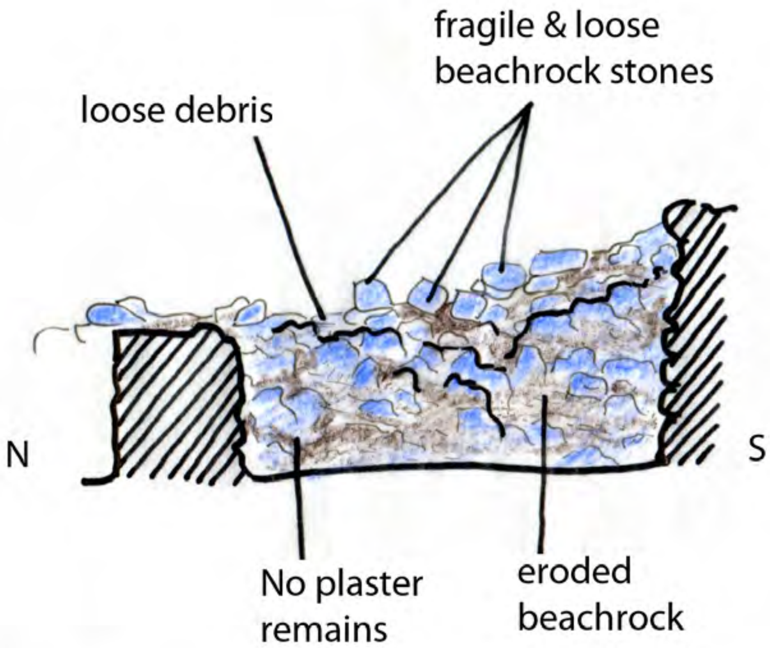

Window at palace after consolidation (03/2012)


Doorway at palace before consolidation (01/2012)


Doorway at palace after consolidation (03/2012)

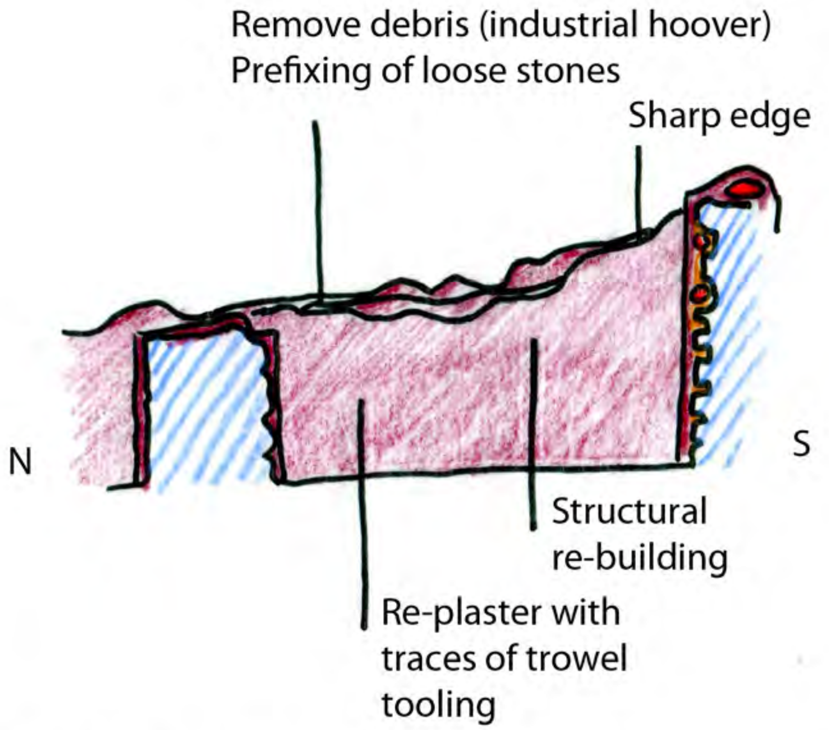
FICHE No.3

# CONSOLIDATION OF WALLS
## RELATED TO HOUSES




Palace (ZUEP04: wall 4091) 1m

State of Conservation December 2011




Palace (ZUEP04: wall 4091) 1m

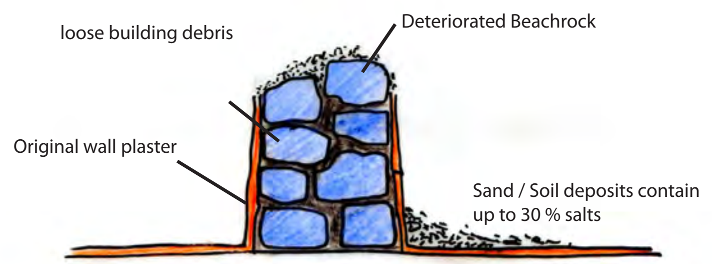
Concept for consolidation February 2012

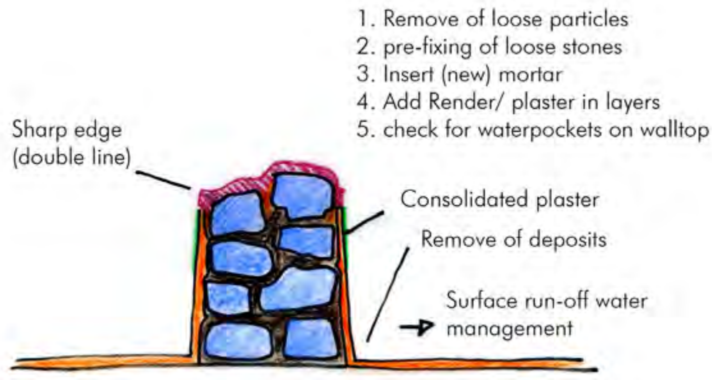
FICHE No.3

# CONSOLIDATION OF WALLS

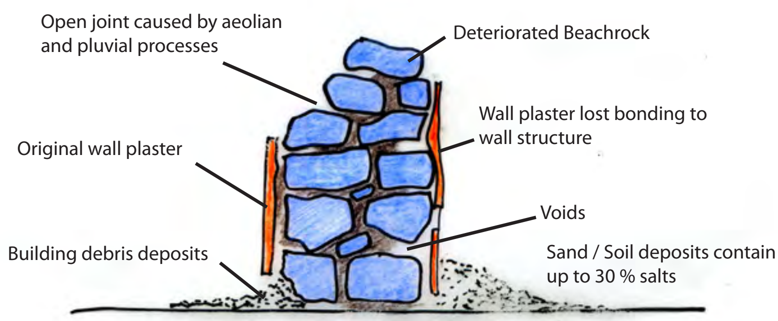
## RELATED TO HOUSES

### SITUATION 1

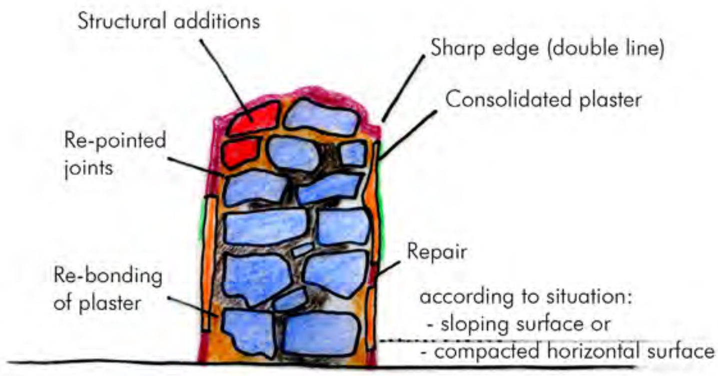



### SITUATION 2




e.g. ZUEP01, Space 102: 604

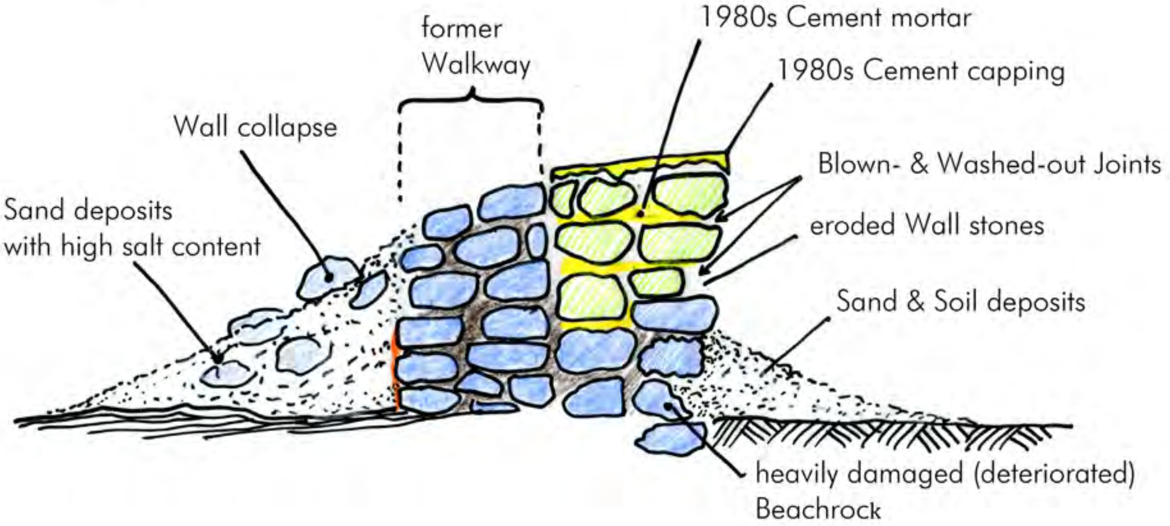


**FICHE No.3**

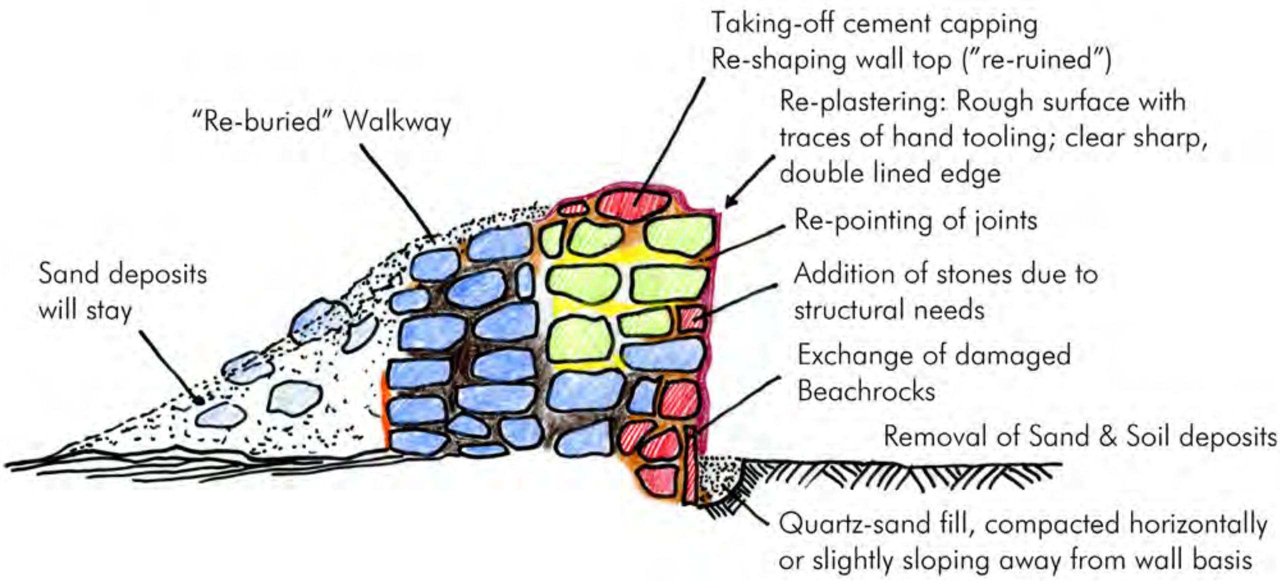
# CONSOLIDATION OF WALLS

## TOWN WALL without exposed walkway

TOWNWALL
CURRENT SITUATION




TOWNWALL
GENERAL CONSERVATION CONCEPT

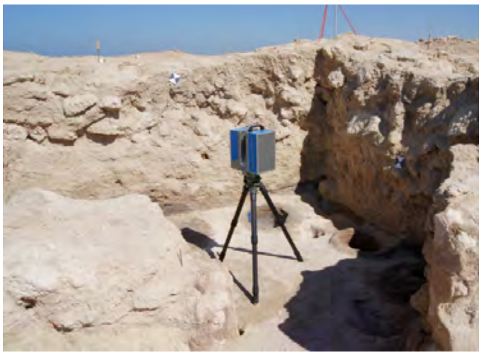


## FICHE No.3.1

# CONSOLIDATION OF WALLS

## PREPARATIONS & INITIAL WORKS

**Field of Application: general**
**PREMISE: Work of Fiche 6 has been executed and documentation is finalised**
**PERSONNEL: surveyer, skilled craftsperson**
**TOOLS: hammer, chisel, pick, brush, hoover, trowel**
**MATERIALS:**



3D-Laser scanning technology is used for documentation and monitoring (M.Kinzel 2011); Cooperation with HafenCity University Hamburg.

Before work can take place, the walls that are being considered for consolidation work have to be recorded and registered in the building inventory (see ***Fiche No.6 – Monitoring and State of Conservation record***). When the documentation is finalised the following procedures should be followed:

1. Hammer out and remove 1980s cement capping

2. Hammer out and remove cement mortar remains in joints.

**FICHE No.3.1**

# CONSOLIDATION OF WALLS

## PREPARATIONS & INITIAL WORKS

3. Expose, strip off and clean collapsed building parts.

4. Remove loose materials and clean with an industrial hoover.

FICHE No.3.1

# CONSOLIDATION OF WALLS

## PREPARATIONS & INITIAL WORKS

5. Pre-select stone material according to quality and (possibly) field of application

6. Pre-watering of wall stones before mortar is inserted.

FICHE No.3.1

# CONSOLIDATION OF WALLS

NOTES

FICHE No.3.2

# CONSOLIDATION OF WALLS

## WALL FOUNDATIONS

**FIELD OF APPLICATION: Only where NO floors were recorded in the archaeological findings. DO NOT perform when historic wall plaster is preserved on floor level or a historic floor has been recorded.**

**PREMISE: Work of Fiche 3.1 has been executed and finalised**
**PERSONNEL: skilled craftsperson with workmen**
**TOOLS:**
**MATERIALS: KA, LA, BL, qS**
**Mortar No. 1.2**

1. Selection of the suitable stone material [KA (1), LA (2), BL(3)].
2. Work at unstable wall parts in manageable segments to avoid collapse.
3. Excavate wall basis down to 20 cm under the current surface level (Fig.4).
4. Insert vertical stoneslabs (KA or LA) into the trench from ca. 20 cm to 5 cm above ground. Stones set in quartz sand (Fig.5 to 7). Exterior of Wall structure to be consolidated and compacted.
5. Production of needed amounts of mortar mixture (Fig.8).
6. Wall structure: Build-up of interior wall structure with mortar and inserted BL-stone-lumbs as well as smaller stones (Fig.9).
7. Building up wall structure with mortar and BL-stones up to 25 cm above ground level. Re-pointing of joints (Fig.10 - 12).
8. Re-pointing of joints at the wall foundation with mortar no.1.2 (Fig.12)
9. Protect your work segement for at least 12 hours against wind and sun (Fig.13).
Keep the mortar moist during this period!

1

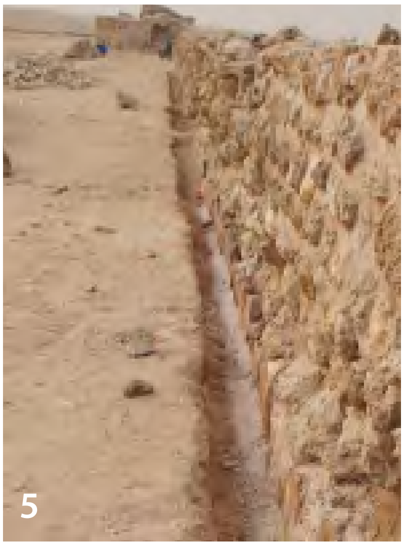
2

3

**FICHE No.3.2**

# CONSOLIDATION OF WALLS


4


5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7


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10

FICHE No.3.2

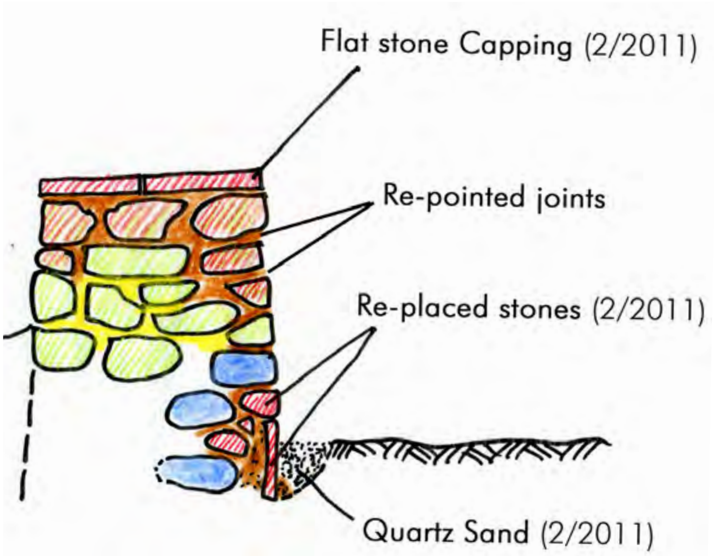
# CONSOLIDATION OF WALLS

## FOUNDATIONS (MAINLY TOWN WALL)


11


12


13




cross-section through consolidated town wall

FICHE No.3.2

# CONSOLIDATION OF WALLS

NOTES

FICHE No.3.3

# CONSOLIDATION OF WALLS

## STRUCTURAL REBUILDING AND STABILISATION

**FIELD OF APPLICATION: all walls**

**PREMISE: Work of Fiche 3.1 has been executed and finalised**

**PERSONNEL: skilled craftsperson with workmen**
**TOOLS:**
**MATERIALS: LO, FR, AG3**
**Mortar No. 1.2 (at walls with remains of historic plasters)**
**Mortar No. 1.51 (ONLY at walls WITHOUT plaster remains!)**

1. Selection of suitable stone material (LO, FR, AG3; Fig. 1 to 3).
2. Preparation of necessary amounts of relevant mortar mixture (Fig.4).
3. Securing and stabilising "open" wall structure by ejecting mortar into voids and caverns (Fig.5).
4. Securing and stabilisation of partly collapsed wall segments by structural re-building; Keep an eye on the joint configuration and the height of courses! (Fig.6)
5. Rebuilding of recognisable shapes by repositioning of stones. Note stone cubatures and joint courses! (Fig. 7 & 8)
6. Re-pointing of joints up close under the stone surface (Fig. 9).
7. Protect area of work for at least 12 hours against wind and sun (Fig. 10). Keep it moist during this period.

DEFINITION:
IF THE ADDITION OF MATERIALS (STONE & MORTAR) GOES BEYOND THE ATTESTED SHAPE OF A STILL RECOGNISABLE WALL STRUCTURE, IT CAN NO LONGER BE CALLED "***STRUCTURAL REBUILDING***" OR "***STABILISATION***". IT HAS TO BE CALLED " ***RECONSTRUCTION***" INSTEAD.

**1**

**2**

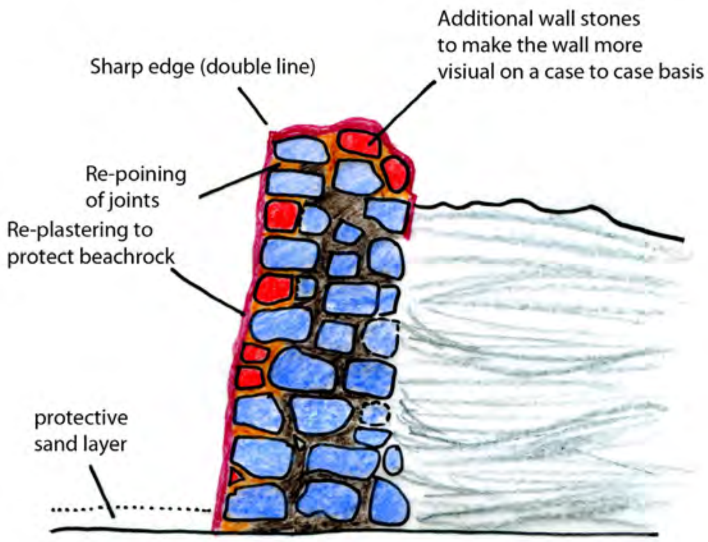
**3**

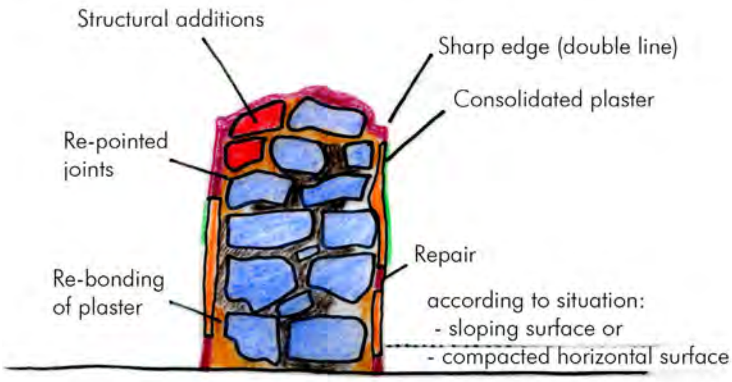
FICHE No.3.3

# CONSOLIDATION OF WALLS
## STRUCTURAL REBUILDING

### Mortars

- Use **mortar No. 1.2** at walls with remains of historic plasters.
- Use **mortar No. 1.51** ONLY at walls WITHOUT plaster remains!



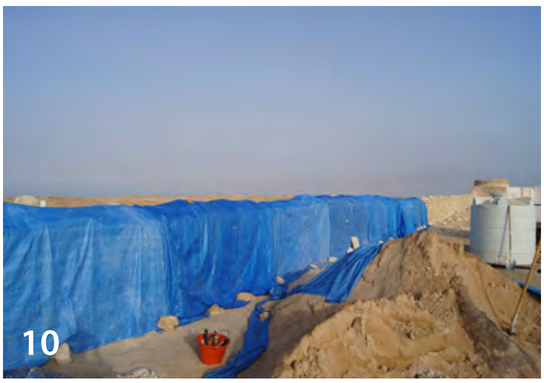
# CONSOLIDATION OF WALLS

## STRUCTURAL REBUILDING

7

8

9



10

FICHE No.3.3

# CONSOLIDATION OF WALLS

## STRUCTURAL REBUILDING

**NOTES**

FICHE No.3.4

# CONSOLIDATION OF WALLS

## RECONSTRUCTION

**FIELD OF APPLICATION: general, but only according to detailled planning!**
**PREMISE: Work of Fiche 3.1 and 3.3 has been executed and finalised**
**PERSONNEL: skilled craftsperson with workmen**
**TOOLS:**
**MATERIALS: LO, FR, AG3**
**Mortar No. 1.2 (at walls with remains of historic plasters)**
**Mortar No. 1.51 (ONLY at walls WITHOUT plaster remains!)**

1. Selection of suitable stone material (Fig. 1 to 3).
2. Preparation of needed amounts of mortar mixtures (Fig.4).
3. preliminary dry-setting of wall stones of the area to be reconstructed; selection of stone cubature (Fig. 5).
4. After moistening of the wall structure and selected stones, build up prepared areas (Fig.6).
5. Raise wall-tops to ensure good surface-run off of water (e.g. rainfall). Set stones in mortar and re-pointing of joints (Fig.7 & 8).
6. Reconstruction and shaping of building features, e.g. steps, door recess according to aproved planning documents (Fig.9, 10 and 11).
7. Protect your work segment at least for 12 hours against sun and wind (Fig.12). Keep it moinst and re-moist it in regular intervals!

DEFINITION:
IF THE ADDITION OF MATERIALS (STONES & MORTAR) GOES BEYOND THE ATTESTED SHAPE OF A STILL RECOGNISABLE WALL STRUCTURE, IT CAN NO LONGER BE CALLED "***STRUCTURAL REBUILDING***" OR "***STABILISATION***". IT HAS TO BE CALLED " ***RECONSTRUCTION***" INSTEAD.

**1**

**2**

**3**

FICHE No.3.4

# CONSOLIDATION OF WALLS

## RECONSTRUCTION


4


5


6


7

# CONSOLIDATION OF WALLS

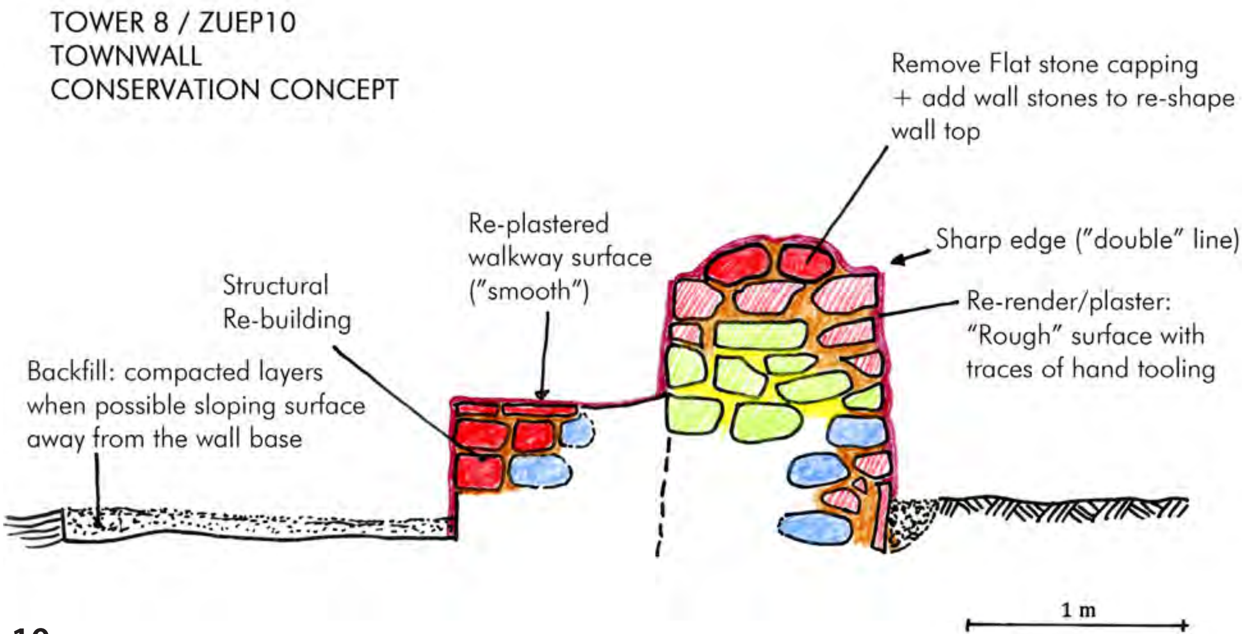
## RECONSTRUCTION


8


11


9


12



FICHE No.3.4

# CONSOLIDATION OF WALLS

## RECONSTRUCTION

### NOTES

**FICHE No.3.5**

# CONSOLIDATION OF WALLS

## PLASTER

**FIELD OF APPLICATION: all wall surfaces - performance according to Fiche No.4!**
**PREMISE: Work of Fiches 3.1, 3.3 and 3.4 has been executed and wall consolidation should be finished TWO weeks before plaster works are scheduled.**
**PERSONNEL: skilled craftsperson with workmen**
**TOOLS: Mortar mixer, trowel, small trowel, sponge, gloves**
**MATERIALS:**
**Mortar No. 1.55 (ONLY at walls WITHOUT plaster remains!)**
**Mortar No. 1.56 ( at walls WITH historic plaster remains)**
**Immediately followed by**
**Fiche No. 3.5.1 (smooth surface), 3.5.2 (hand tooling), or 3.5.3 (rough surface)!**

1. Preparation and production of needed plaster mix (Fig.1)
2. ***First application:*** Even out irregularities, but follow the general form, keeping general unevenness. Plaster mortar should be inserted without smoothing. After ca. 2-3 hours scratch off peaks. This plaster layer can be 1 to 5 cm thick. Shrinkage cracks will appear. Design details have to prepared and pre-shaped in this phase. Cover plaster with fabric! (Fig. 2, 3 & 4).
3. ***Second application***: after approx. 6 -24 hours. The underground (1st application) can be partly dried. Pre-watering of wall segment. Apply plaster mortar and strip it off. Don't smoothen it. Plaster mortar application should not be more than 3 cm. There could still appear some shrinkage cracks. Design details have to be shaped. Plaster has to be covered with fabric (Fig. 5, 6, 7, 8 & 9).
4. ***Third application:*** after approx. 2 - 4 hours. 2nd application should be solid and not mouldable with the thumb. Apply plaster material with trowel and smoothen surface with a small trowel in vertical segments. Some visual traces of trowel tooling are desired (see **Fiche No. 3.5.1**). Plaster mortar should be applied in layers of max.1,5 cm thickness. Design details should be shaped and completed by now. Cover plaster with fabric! (Fig.10, 11, 12 & 13).
5. Protect your work segment for at least 12 hours against sun and wind! Cover the surfaces with fabric (Fig. 14). Keep the plaster humid. (Fig.15).

**NOTE:** Applied wall plaster should cover approx. 10 cm of the wall top to create an area which forms a ledge once the wall capping is applied (see **Fiche No. 3.5.3**)! Salt crystallized on the surface should be brushed off after 40 to 50 hours!

FICHE No.3.5

# CONSOLIDATION OF WALLS

## PLASTER


1


2


3


4


5


7


6

FICHE No.3.5

# CONSOLIDATION OF WALLS

## PLASTER


8


9


10


11


12


13


14


15

FICHE No.3.5

# CONSOLIDATION OF WALLS

## PLASTER

NOTES

**FICHE No.3.5.1**

# CONSOLIDATION OF WALLS

## PLASTER DESIGN “Smooth surface”

**FIELD OF APPLICATION: Building structures, Interior - wall faces (including features as niches, recessess, Doorways, etc..)**
**PREMISE: Work of Fiches 3.5 has been executed .**
**PERSONNEL: skilled craftsperson with workmen**
**TOOLS:**
**MATERIALS:**
**Mortar No. 1.55 (ONLY at walls WITHOUT plaster remains!)**
**Mortar No. 1.56 ( at walls WITH historic plaster remains)**
**Follows directly on Fiche 3.5!**

1. After approx. 30mins. to 1.5hours the mortar should be not mouldable by thumb pressure.
2. Expose, carefully, quartz particles at the surface with sponge and water. Avoid sponge traces.
3. Afterwards, smooth surface with a small trowel. Traces of trowel tooling can stay visible.
4. Steps 2 and 3 (sponge/small trowel treatment) has to repeated over approx. 4hours with short breaks of approx. 15 to 45mins.
5. Surface should be kept humid over the entire work period.
6. Mortar has to be covered in between.

1. nach ca. 30 min. bis 1,5 Stunden sollte der Mörtel auf Daumendruck nicht mehr formbar sein.
2. Mit Schwamm und Wasser werden vorsichtig die Partikel in der oberen Schicht leicht freigewaschen. Schwammspuren sind zu vermeiden.
3. Anschließend wird mit einer kleineren Kelle die Oberfläche nachgeglättet. Kellenspuren dürfen dabei sichtbar bleiben.
4. Der Vorgang mit Schwamm vorsichtig waschen und mit kleiner Kelle Oberflächen nachziehen muss ca. 4 Stunden lang mit Pausen von ca. 15-45 min. wiederholt werden.
5. Der Oberfläche ist über den gesamten Zeitraum genügend Feuchtigkeit anzubieten.
6. Mörtel mit Folie zwischendurch abdecken.

**FICHE No.3.5.1**

# CONSOLIDATION OF WALLS

## PLASTER DESIGN " Smooth surface"





**FICHE No.3.5.2**

# CONSOLIDATION OF WALLS

## PLASTER DESIGN " Hand tooling"

**FIELD OF APPLICATION: in general on "exterior" wall faces at the palace, the town wall and towers (Check archaeological record!).**

**PREMISE: Work of Fiches 3.5 is executed!**

**PERSONNEL: skilled craftsperson with workmen**
**TOOLS: Trowel, sponge, water-sprayer**
**MATERIALS:**
**Mortar No. 1.55 (ONLY at walls WITHOUT plaster remains!)**
**Mortar No. 1.56 ( at walls WITH historic plaster remains)**

**Follows immedidiately after Fiche No. 3.5!**
Mortar can still be mouldable by thumb pressure.

1. Treatment of mortar surface with gloves, hessian or linen-bales to create traces of hand tooling.
2. The surface appearance suggests that the plaster was applied entirely by hand.
3. Surface has to be kept humid during the entire work period.
4. Mortar should be covered with fabric in between.

1. Mit Handschuh und Jurte- oder Leinenballen wird die Oberfläche aufgestrichen und abgerieben, so daß Hand- bzw. Fingerabdrücke in dem Mörtel hinterlassen werden.
2. Die Oberfläche erhält so ein Design, dass es scheint, der Mörtel ist komplett mit der Hand aufgetragen worden.
3. Der Oberfläche ist über den gesamten Zeitraum genügend Feuchtigkeit anzubieten.
4. Mörtel mit Folie zwischendurch abdecken.

FICHE No.3.5.2

# CONSOLIDATION OF WALLS

## PLASTER DESIGN "Hand tooling"

1. Building up of mortar layers

2. Applying final render by hand with gloves...

3. Final appearance with "tools".

**FICHE No.3.5.3**

# CONSOLIDATION OF WALLS

## PLASTER DESIGN " Rough surface"

**FIELD OF APPLICATION: all wall cappings where NO historic wall top/crown is preserved**
**PREMISE: Work of Fiches 3.5 has been executed ; When used for wall capping the wall faces (Fiche 3.5.1 or 3.5.2) should be finalised before!**
**PERSONNEL: skilled craftsperson with workmen**
**TOOLS: Trowel, Sponge**
**MATERIALS: Water**
**Mortar No. 1.55 (ONLY at walls WITHOUT plaster remains!)**
**Mortar No. 1.56 ( at walls WITH historic plaster remains)**

**Follows immediately after Fiche 3.5!**

1. after 30 mins. to 1.5 hours the mortar should be not be mouldable by the thumb anymore.
2. Exposure of quartz particles at the surface by trowel, sponge and water; repeat procedure if necessary (Fig. 1 to 3).
3. This procedure applies a rough but regular appearance to the mortar surface (Fig.5).
4. Surfaces should be kept humid during the entire work period. (Fig.4)
5. Mortar should be covered with fabric in between the work steps.

1. nach ca. 30 min. bis 1,5 Stunden sollte der Mörtel auf Daumendruck nicht mehr formbar sein.
2. Mit Kelle, Schwamm und Wasser werden die Partikel in der oberen Schicht freigekratzt, ggf. Vorgang mehrfach wiederholen.
3. Der Mörtel erhält so ein rauhes aber gleichmäßiges Erscheinungsbild.
4. Der Oberfläche ist über den gesamten Zeitraum genügend Feuchtigkeit anzubieten.
5. Mörtel mit Folie zwischendurch abdecken.

# FICHE No.3.5.3

# CONSOLIDATION OF WALLS

## PLASTER DESIGN " Rough surface"

1

2

3

4

5

**FICHE No.3.5.4**

# CONSOLIDATION OF WALLS

## REPAIR OF CRACKS appearing in new plaster

**FIELD OF APPLICATION: general when cracks appear on plaster surfaces**
**PREMISE:**

**PERSONNEL: skilled craftsperson with workmen**
**TOOLS: Trowel, sponge, water-sprayer**
**MATERIALS:**
**Mortar No. 1.55 (ONLY at walls WITHOUT plaster remains!)**
**Mortar No. 1.56 ( at walls WITH historic plaster remains)**

1. Open surface cracks with trowel and clean the area with brush.
2. Water plaster / mortar and mix amounts of mortar required.
3. Fill opened crack with mortar.
4. Adjust mortar to surrounding surface.

FICHE No.3.5.4

# CONSOLIDATION OF WALLS

## PLASTER REPAIR

NOTES

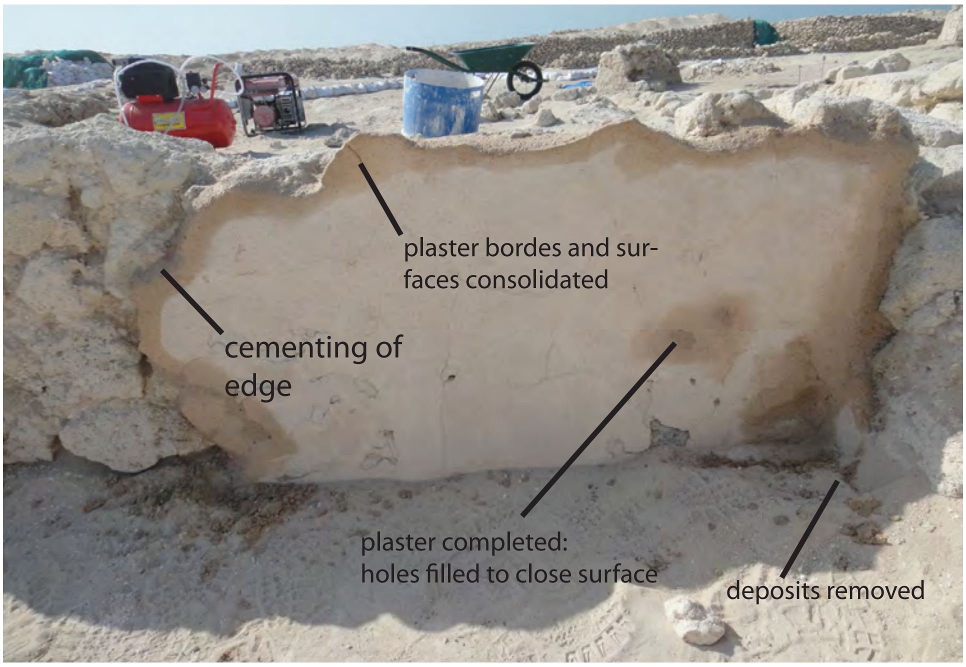
FICHE No.4

# CONSOLIDATION & STABILISATION
## OF HISTORIC PLASTERS & SURFACES

**FIELD OF APPLICATION: general**
**CLIMATE Conditions:**
**PREMISE: Performance <u>before</u> Fiche No. 3.5!**

**PERSONNEL:** experienced conservator/restorer with trained assistant
**TOOLS:** Brushes, Industrial hoover, spatulae, trowel, bucket, sponge, water-spray
**MATERIALS:** Water, acryl-dispersion, Lime, Sand

Before consolidation took place (ZUEP02)




Immediately after the consolidation took place.

**FICHE No.4**

# CONSOLIDATION
## OF HISTORIC PLASTER SURFACES

Consolidation of Plaster surfaces
see Fiche No. 4.1

Consolidation of Plaster surfaces
see Fiche No. 4.1

Fixing of loose plaster parts
see Fiche No. 4.2

Cementing of Cracks
see Fiche No. 4.3

# FICHE No.4.1

# CONSOLIDATION
## OF HISTORIC PLASTER SURFACES

**FIELD OF APPLICATION: general**
**Climate conditions:** Avoid direct sun and too strong winds (max 5Bft & max 28°C)

**PREMISE: Performance before Fiche No. 3.5!**

**PERSONNEL:** One or two skilled restorer
**TOOLS:** Brushes, Industrial hoover, spatulae, trowel, bucket, sponge,
**MATERIALS:** Water, acryl-dispersion, Lime
**EXTRA:**

### Introduction

The historic plasters have an enormous complexity and range of preservation. This work should be executed and supervised by a conservator/Dipl.-Restorer experienced in conservation in the context of archeological field work.

### Conservation works

Before the conservation works, all extremely deformed and loose fragments of the wall plaster, as well as debris materials, need to be carefully removed using an industrial hoover.
To fill gaps, cracks, and voids a specially composed mortar is used, which is based on 1 part lime, Acryl-dispersion (2%), and 4 parts „desert sand".


2

1. Preparation and mixing of Consolidation liquids (Acryl-dispersion SF016 7% in Water) (fig. is missing).

2. Cleaning of plaster surfaces with brushes and hoover (Fig.2).


3

3. regular application of consolidation liquid onto the plaster surface (Fig.3 & 4) .


4

4. repeat point 3 after 5 to 10 minutes according to absorbency of plaster subsurface. However additional application should be executed wet in wet (Fig.6).

## FICHE No.4.1

# CONSOLIDATION
OF HISTORIC PLASTER SURFACES

**NOTE**: AIM OF MEASURE IS TO STABILISE THE HISTORIC PLASTER SURFACES TO REDUCE WEATHERING EFFECTS. DUE TO THE HIGH SALINITY INSIDE THE MORTARS AND WALLSTRUCTURES THE DETERIORATION CANNOT BE STOPPED COMPLETELY.




NOTES

FICHE No.4.2

# CONSOLIDATION OF PLASTER

## FIXING OF LOOSE & BROKEN PLASTER PIECES /PARTS

**FIELD OF APPLICATION: general**
**Climate conditions:** Avoid direct sun (max. 28°C) and too strong winds (max. 5Bft)
**PREMISE: Fiche No. 4.1 has to be executed before!**
**PERSONNEL:** One or two skilled restorer
**TOOLS:** Brushes, Industrial hoover, spatulae, trowel, bucket, sponge, drill, saw
**MATERIALS:** Water, acryl-dispersion, fibre glas rods
**EXTRA**: Avoid direct sun and too strong winds

### A - Securing detached plaster by needling

1. Prepare anchor material (fiberglass rods D 4-8 mm), define drilling range, quantity and length of needling and deployed anchors (Fig. 1).
2. Drilling holes with 2mm wider diameter than desired anchor material; make sure that the holes are pointing in different directions, but drilled slightly diagonally downward (Fig. 2)
3. Cleaning of the dowel hole and prewetting (Fig. 3)
4. Glue/Fixing of dowel rods. Glue: here Lime-Acryl milk (Fig.4)
5. Closure of the dowel holes with mortar (see Fiche 4.3), (Fig.5)


1


2


3


4


5

FICHE No.4.2

# CONSOLIDATION OF PLASTER

## FIXING OF LOOSE & BROKEN PLASTER PIECES /PARTS

**B - Re-attaching broken plaster parts by needling**

6. Recover and securing fragments, Cleaning of fragments (Fig.6)
7. Mapping, sorting, and reconstruction of the original position (Fig.7).
8. Bonding of the fragments as required (Fig.8)
9. Preparation of needling (as described in paragraph A), (Fig.9)
10. Re-attachment and bonding of fragments in its historical position (Fig. 10 & 11).
11. Seal dowel holes and joints with mortar (Fig.12)


6

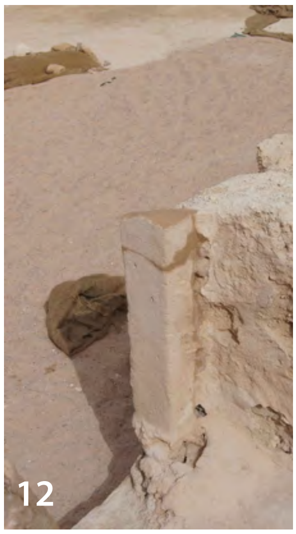

7


8


9


10


11


12

FICHE No.4.3

# CONSOLIDATION OF PLASTER

## CEMENTING OF CRACKS AND LOOSE PLASTER PARTS

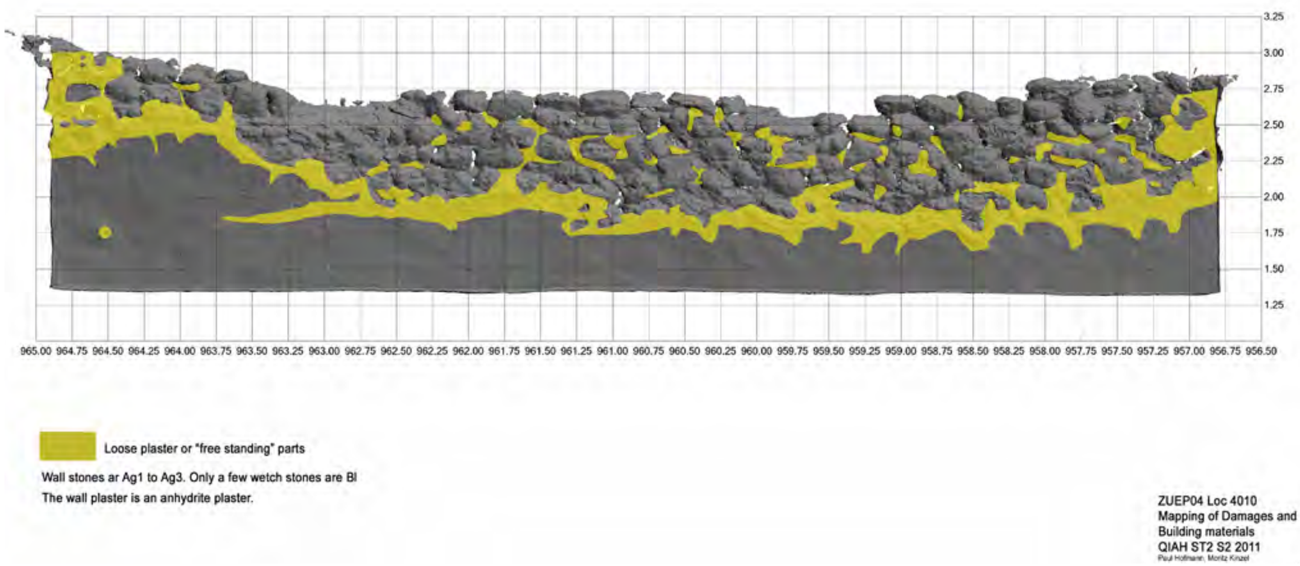
**FIELD OF APPLICATION: general**
**CLIMATE CONDITIONS:** Avoid direct sun (max. 28°C) and too strong winds (max. 5Bft)

**PREMISE: Fiche No. 4.1 has to be executed before!**

**PERSONNEL:** One or two skilled restorer
**TOOLS:** Brushes, Industrial hoover, spatulae, trowel, bucket, sponge
**MATERIALS:** Water, Acryl-dispersion, Repair plaster (1RT wLh, 4 RT ds, 2%SF016 in water)

1. Cleaning of plaster borders with brush, hoover and lancettes (Fig. 1 & 2)
2. Mixing of repair plaster (1RT wLh, 4 RT ds, 2%SF016 in water) in an amount that can be used within 1 hour (Fig. 3)
3. Application of repair plaster after pre-watering to the level of the historic plaster surface: closing of holes and cracks, bridging areas to be prepared for later replastering (Fig. 4 to 6).
4. After 10 to 13 min.: Secondary- treatment with sponge, Exposure of granulation, smoothing and cleaning of plaster borders (Fig.7).
5. Protect your area of work for at least 12 hours against wind and sun (Fig.8). Keep it humid during period.

NOTE: Aim of measure is to stabilise the plaster surfaces with completing the historic plaster; including filling of holes, gaps and cracks. Border line between historic remains and additional replastering (see Fiche No. 3.5) has to be defined with the responsible conservation architect in forehand.



FICHE No.4.3

# CONSOLIDATION OF PLASTER

## CEMENTING OF CRACKS AND LOOSE PLASTER PARTS








FICHE No.5

# PROTECTION

## OF ARCHITECTURAL AND ARCHAEOLOGICAL REMAINS

**FIELD OF APPLICATION: general**
**Climate conditions: Avoid to heavy winds.**
**PREMISE: Work is finished for the season or it was decided to backfill**
**PERSONNEL: Trained workmen under supervision**
**TOOLS: Sieve, Wheelbarrows, Shovel, Brush, Stomper**
**MATERIALS: Sieved soil and/or quartz sand and sand bags, mesh/membrane , Hessian**
**EXTRA**: Protect yourself against dust and fine sand particles during the work.

## GENERAL GUIDELINES

Damage to architectural and archaeological remains should be avoided in general. Damage to the fragile vestiges should be minimised by the following preventive measures:

1. Careful handling of tools, especially wheelbarrows to avoid scratches and colour marks on historic plaster surfaces or door reveals.
2. preventive covering of architectural/archaeological features
3. Clearly marking closed areas with restricted access.
4. Cover plaster floor with mesh and sand layer. Use planks for working tracks.

FICHE 5.1 BACKFILL (TEMPORARY AND PERMANENT)
FICHE 5.2 STABILISATION AND PROTECTION

FICHE No.5

# PROTECTION
## OF ARCHITECTURAL AND ARCHAEOLOGICAL REMAINS

NOTES

FICHE No.5.1

# PROTECTION

## BACKFILL - TEMPORARY BACKFILL

**FIELD OF APPLICATION: general**
**Climate conditions: avoid too strong winds**
**PREMISE:**
**PERSONNEL: Supervisor, trained labour**
**TOOLS: Wheelbarrow, shovel, stomper, cutter, etc.**
**MATERIALS: sieved soil or quartz sand, sand bags (size depends on context), Membrane (Geotextile/Tyvek ), Hessian or Mesh,**
**EXTRA:**

TEMPORARY BACKFILL will take place in areas with ongoing archaeological investigations or when consolidation work cannot take place immediately after the archaeological record is done.

The backfill should always be carried out in a way that can be easily taken out or removed again for work to continue. In principle, the temporary backfill should be carried out as carefully as a permanent one, but with the premise that archaeological/architectural remains should be protected until conservation work can take place. Therefore only sieved material or quartz sand should be used.

No stone or beachrock lumps as well as wall plaster chunks should be in the backfill material. Walls should be covered first with a membrane, mesh or hessian fabric before and bags placed along the wall structures to protect against collapse.

Backfill should be done high enough to cover wall faces and wall tops. Avoid water pools in the backfill area. Try to create a sloping surface away from the walls and wall base.

**DO NOT**
use unsieved soil from the spoil heaps mixed with stone material

**DO**
only use sieved soil or quartz sand for backfill

# PROTECTION

## BACKFILL - PERMANENT BACKFILL

PERMANENT BACKFILL will take place when areas or features will not be presented to the public. Backfill should be done carefully to avoid collapse of building structures and trench profiles. Layers should be compacted. In the beginning, horizontally laid sand/soil layers should be built up. Finally, some sloping should be implemented to ensure a quick run-off of surface water away from wall foundations.

More fragile archaeological features have to be stabilised and covered separately beforehand. This has to be discussed and agreed upon with the responsible archaeologist / conservation coordinator.



Backfill with sieved soil or quartz sand in compact layers;
Layers should be horizontal or slightly sloping away from wall foundations to avoid damages by run-off surface water; Final layer should be compacted by stomping or mechanical vibrations if NO fragile archaeological features are attested.

FICHE No.5.2

# PROTECTION

## STABILISATION & PROTECTION

**FIELD OF APPLICATION: general**
**Climate conditions:**
**PREMISE:**
**PERSONNEL:**
**TOOLS: Cutter, Wheelbarrow**
**MATERIALS: Sand, Soil, Sandbags, Mesh, Hessian**
**EXTRA:**

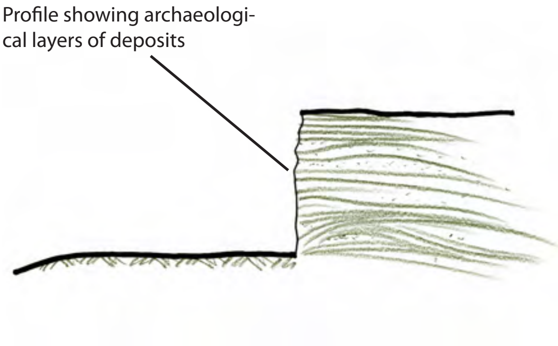
Protect features and building elements against human impact. Door recesses should be protected with sandbags and fragile walls or profiles should be stabilised accordingly. Sandbags can also be used to limit access to specific areas, e.g. stairs or rooms. Using Sandbags is an easy and simple solution. For several reasons (UV-protection, aesthetics) bags made of plastic fabric should be covered with hessian or comparable materials. To fill sandbags only, sieved soil should be used to avoid damage caused by stones inside the sandbag.

If you have to remove a temporary stabilisation by sandbags, be careful to avoid damage to the protected walls and features. Additional protective measures may be necessary once the sandbags are removed.

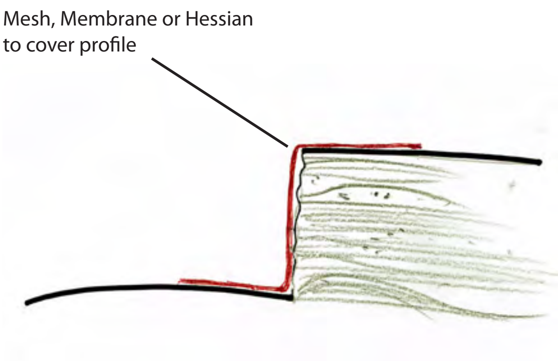
FICHE No.5.2

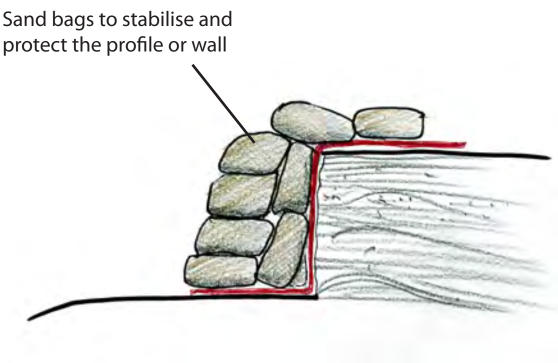
# PROTECTION

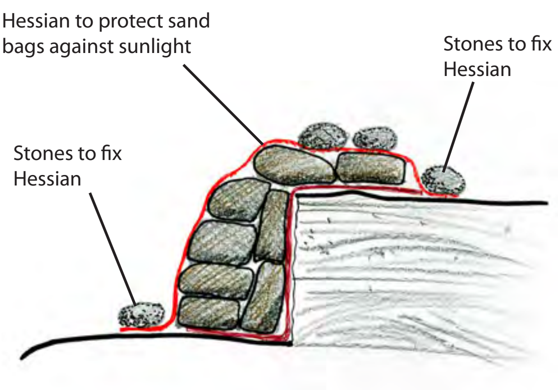
## STABILISATION & PROTECTION




To protect the walls or trench borders/profiles, the following preventive measures should be used: 1. Cover the remains/profiles with mesh/membrane or hessian. 2. Place sandbags in front of the segment to protect and stabilise.
3. The sandbags should be covered with hessian to provide protection against UV-sunlight.
4. Keep the hessian in position with stones placed on top and bottom.




FICHE No.6

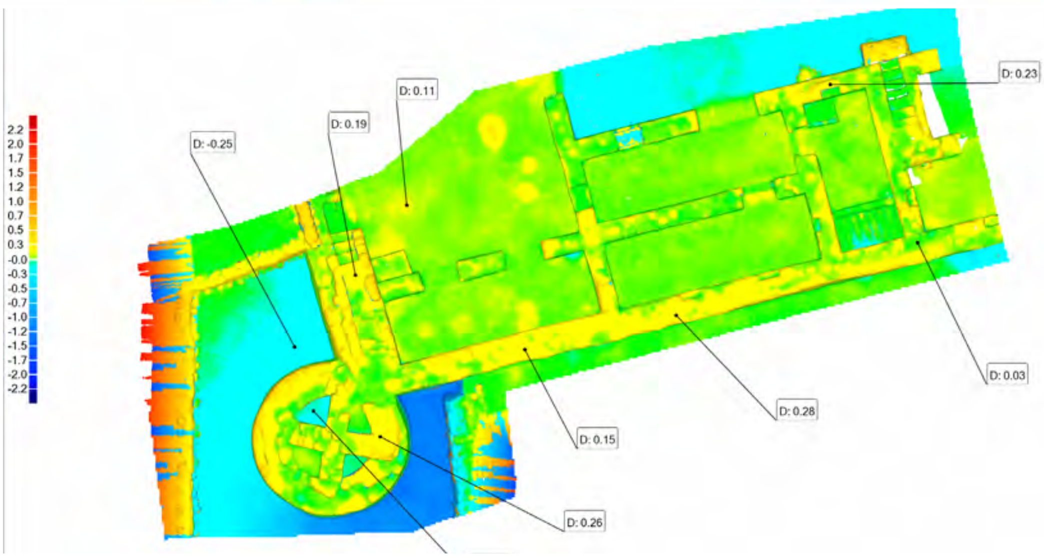
# MONITORING

## STATE OF CONSERVATION

**FIELD OF APPLICATION: general, in regular intervals**
**related Fiches:**
Fiche 6.1 State of conservation Record
Fiche 6.2 Record of Climate Data
Fiche 6.3 (Conservation) Site Journal
Fiche 6.4 Indicators and Periodicity

MONITORING has to be done in regular intervals. For details see defined indicators and interval recommendations in the Management Plan for ASAZ (Chapter 11, Tab.5 -p.75; Summary on Fiche 6.4).

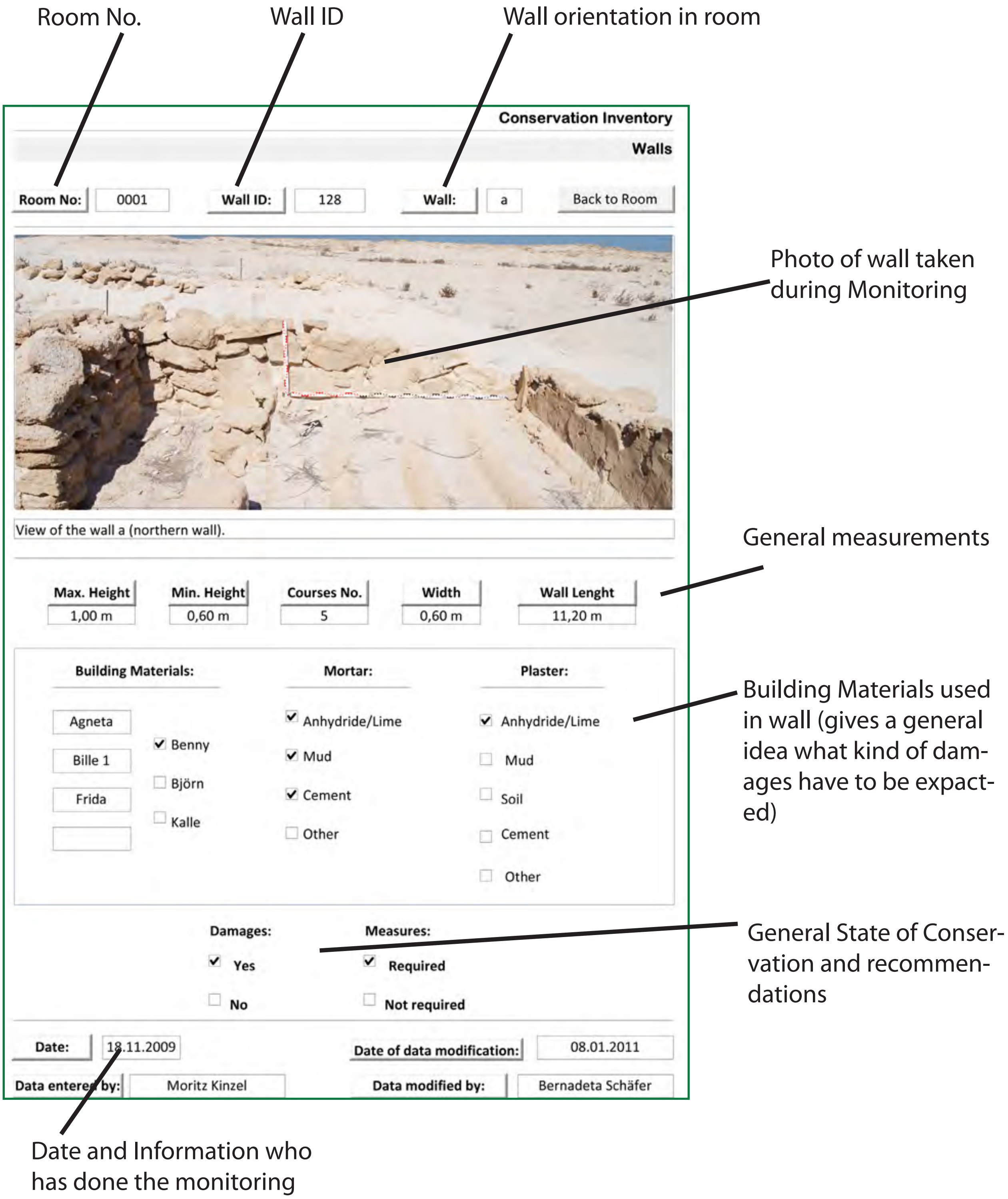
WORK STEPS:
1) Photograph, Analog Data sheet (entry into digital inventory data base)
2) Mapping of Damages etc. on plan, photos, scan...
3) 3D-Laserscan and interpolation with earlier scans to show changes, interventions, etc.
4) Analyses of monitoring data and preparation of state of conservation report
5) Development of priority list for conservation measures and repairs according to monitoring record analyses.

**FICHE No.6.1**

# MONITORING

## State of Conservation Inventory




Conservation Inventory

Walls

Room No: 0001 | Wall ID: 128 | Wall: a | Back to Room

| Max. Height | Min. Height | Courses No. | Width | Wall Lenght |
|---|---|---|---|---|
| 1,00 m | 0,60 m | 5 | 0,60 m | 11,20 m |

| Building Materials: | | Mortar: | Plaster: |
|---|---|---|---|
| Agneta | ☑ Benny | ☑ Anhydride/Lime | ☑ Anhydride/Lime |
| Bille 1 | ☐ Björn | ☑ Mud | ☐ Mud |
| Frida | ☐ Kalle | ☑ Cement | ☐ Soil |
| | | ☐ Other | ☐ Cement |
| | | | ☐ Other |

| Damages: | Measures: |
|---|---|
| ☑ Yes | ☑ Required |
| ☐ No | ☐ Not required |

Date: 18.11.2009 | Date of data modification: 08.01.2011

Data entered by: Moritz Kinzel | Data modified by: Bernadeta Schäfer

The state of conservation should be recorded before conservation measures take place. The actual state should be also documented after the conservation measure has taken place. Then monitoring should take place on a regular basis according to the recommended interval mentioned in the inventory data base. Regular monitoring helps to identify threads to the remains and to initiate maintenance work to protect the fragile vestiges (see also Appendix 10).

## FICHE No.6.1

# MONITORING

## State of Conservation Inventory

The state of conservation record at AZAS is kept in an Inventory Database (Microsoft Office 2010 Access-based).

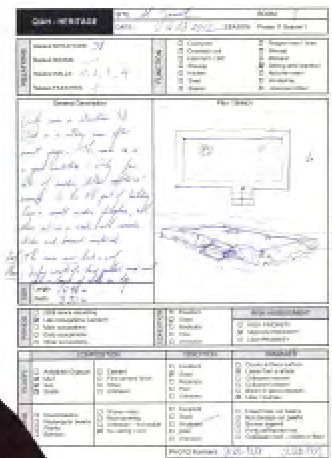
Data record should be supervised by conservation architects or restorers and executed by trained/skilled staff, using photographs, 3D-laserscans and written comments and/or analyses of defects. On the basis of the 3D-laserscans and images plans should be produced to map the damages and deterioration patterns.Overlays of 3D-laserscans can be used to document structural changes and conservation measures. Manual recording should be digitalized.

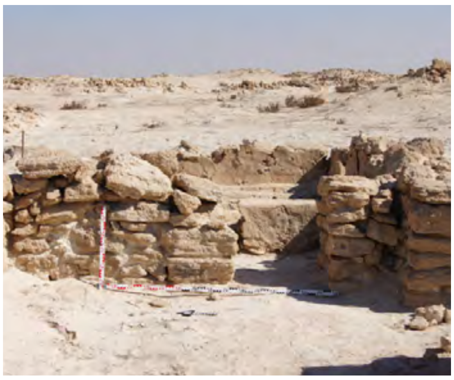
(see also APPENDIX 9.5 and APPENDIX 10)

| | | | |
|---|---|---|---|
| *Az Zubarah* | Documentation State of Preservation | | 2009 |
| old excavation area | South field | Catalogue | |
| R.005 | **Wall d** | Date: 18.11.2009 | |

| Description | Consolidation/Conservation suggestions |
|---|---|
| Extreme weathered, eroded beach-stone.<br>Partly collapsed wall face. Collapsed parts of the cement top coating.<br>At wall base: deposits of washed out beach-stone material, mortar, etc.<br>high concentration of salt.<br>Holes and voids in the wall structure,<br>partly "free standing" wall plaster;<br>joints are blown out and the construction can't bear any loads.<br>In southern part, lower 1/3 still some areas of "original" plaster preserved. | |

above: Example of the Inventory record for the *fortified Compound* (QMA4) done in 2009.

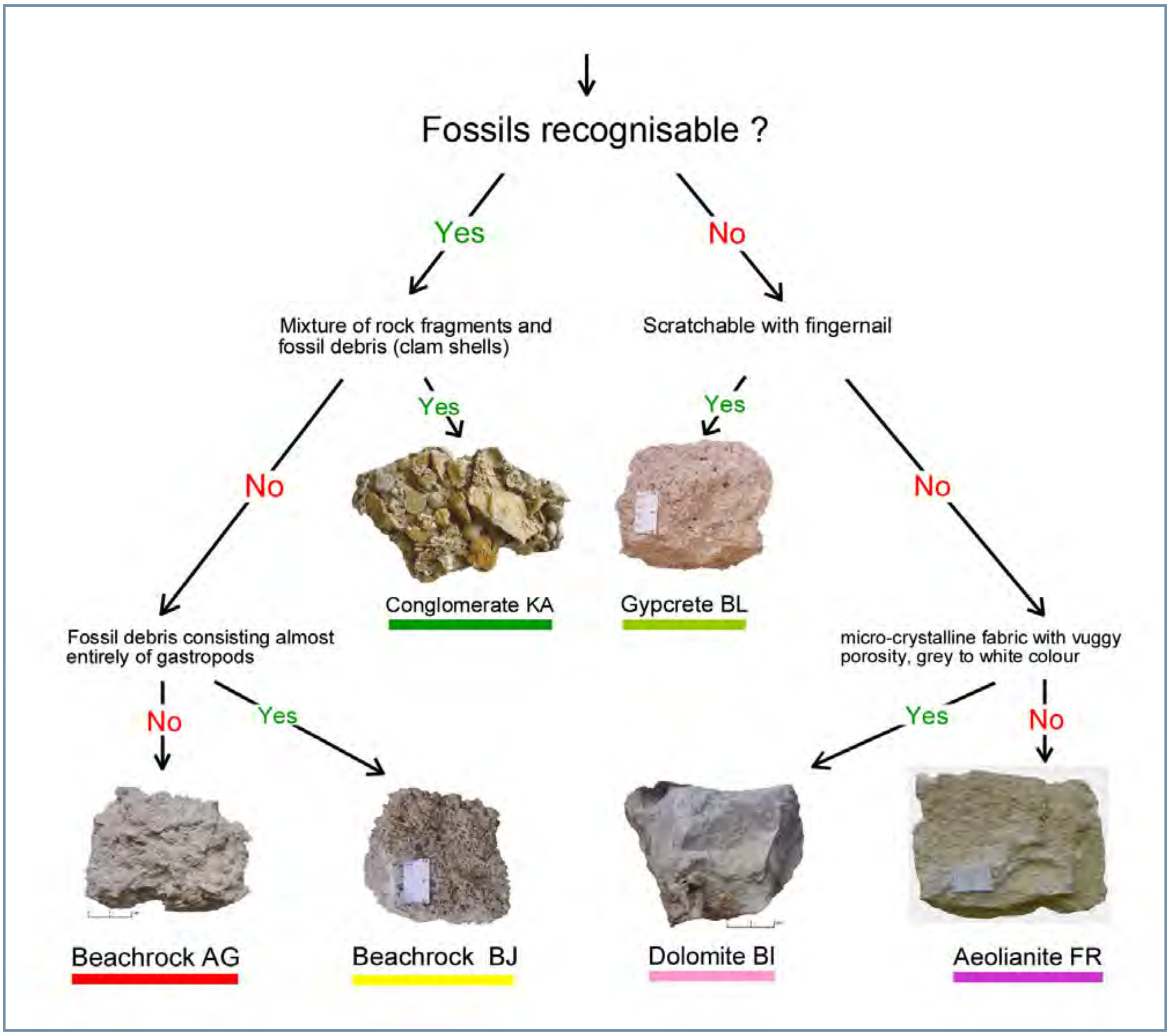




# FICHE No.6.1

# MONITORING
## State of Conservation Inventory

### IDENTIFICATION SCHEME FOR BUILDING STONES
with colour code for mapping



## FICHE No.6.2

# MONITORING

## Climate Record

At Al Zubarah several data loggers are installed permanently (for locations see map below). The recorded data has to be downloaded from the single devises regularly, at intervals of three to six months. Data should be uploaded to the project server immediately.

Data loggers have to be reset according to the technical manual, before they are placed back. At the same time the batteries should be checked. **Make sure that the batteries are replaced in time!**

Temperature/humidity data loggers at QMA2 in Al Zubarah town (D1, D2) and HAB54506 at Al Zubarah Fort.


Fig. 8: Positions of the temperature/humidity data loggers in Al Zubarah town (D1, D2, D4, D5, HAB54579), at the research station (D3), and in a building of the fort (HAB54506)

FICHE No.6.2

# MONITORING

## Climate Record

# FICHE No.6.3

# MONITORING

## Site journal - How to record your work

1. Keep a record of your work
2. Weather conditions: note temperature, wind intensity, and general conditions; whether it is cloudy, sunny, dusty, humid.
3. Who is working: Names of colleagues and workmen (numbers)
4. What are the activities and programme.
5. List any events: visits, injuries, etc.
6. Photo documentation of work: at least one image in the morning (before the work starts), one before the main breaks and one at the end of the work day.
7. Save images to the database with a description (Meta data)!
8. Type in the site journal data and save the report as a pdf (see templates in Appendix 9; especially 9.3 and 9.4).

AL ZUBARAH ARCHAEOLOGICAL SITE

**CONSERVATION SITE JOURNAL**

QATAR ISLAMIC ARCHAEOLOGY AND HERITAGE PROJECT

Heritage | Archaeology | History | Environment

**DAILY REPORT**

Page 1 / 2

Document No.

QIAH-01-02-HE-9000

SITE VISIT from **Monday** [Day]; 17.09.2012 [Date]; 13:00 [Time]

DATE and TIME

Info on Weather

**WEATHER:** **Sunny** **TEMPERATURE** **HUMIDITY**

**ATTENDEES (incl. workmen, crafts persons, etc.)**

Ingolf Thuesen

Who?

**Materials status**
Hydrated Lime
NHL
White Cement
Quartz sand
Soil
Water

Information on materials status and needs for procurement

Where?

**LOCATION: PALACE (ZUEP04)**

**MEASURES, ACTIVITIES, WORK**
(planned for the day, as well as executed)

State of Conservation monitoring

What?

| DRAWINGS / DOCs related<br>Photos taken | Doc. No. | Content | Date | handed over to |
|---|---|---|---|---|

Basis of work and/or how is it documented

**INADEQUACIES** (defects, cracks, detaching, etc)

Historic plaster surfaces are detached, salt crystallization processes, cracks in new sacrificial plaster layers, sand deposits caused by aeolian processes.

State of conservation; challenges, defects, etc.)

**INSTRUCTIONS**

How to solve situation. Recommendations, Proposals, etc.

FICHE No.6.3

# MONITORING

## Site journal

AL ZUBARAH ARCHAEOLOGICAL SITE

**CONSERVATION SITE JOURNAL**

QATAR ISLAMIC ARCHAEOLOGY AND HERITAGE PROJECT

Heritage | Archaeology | History | Environment

**DAILY REPORT**

Page 2 / 2

Repeat Doc. No. here

**QIAH-01-02-HE-9000**

SITE VISIT from **Monday** [Day]; 17.9.2012 [Date]; 13:00 [Time]

Tower 4012 - loss of historic plaster due to salt crystallization.

Wall 4010 - cracks in new wall plaster (sacrificial layer).

Photo of current situation

**SKETCH / COMMENTS**

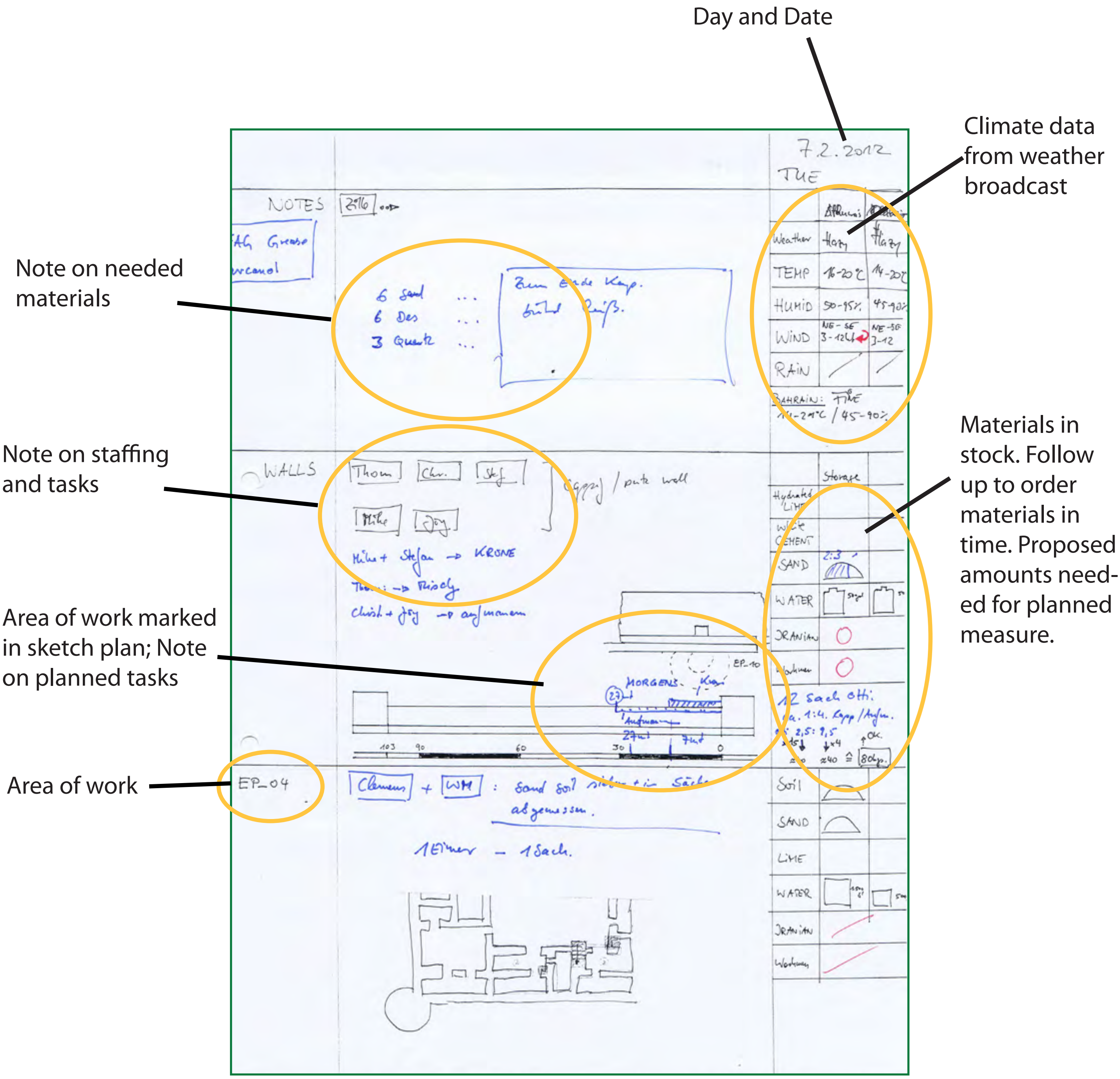
Assessment should be done by experts when the season starts to execute repairs.

additional information, sketches or images explaining the work or specific features, conditions, events, etc.

FICHE No.6.3

# MONITORING

## Site journal - Examples from 2012

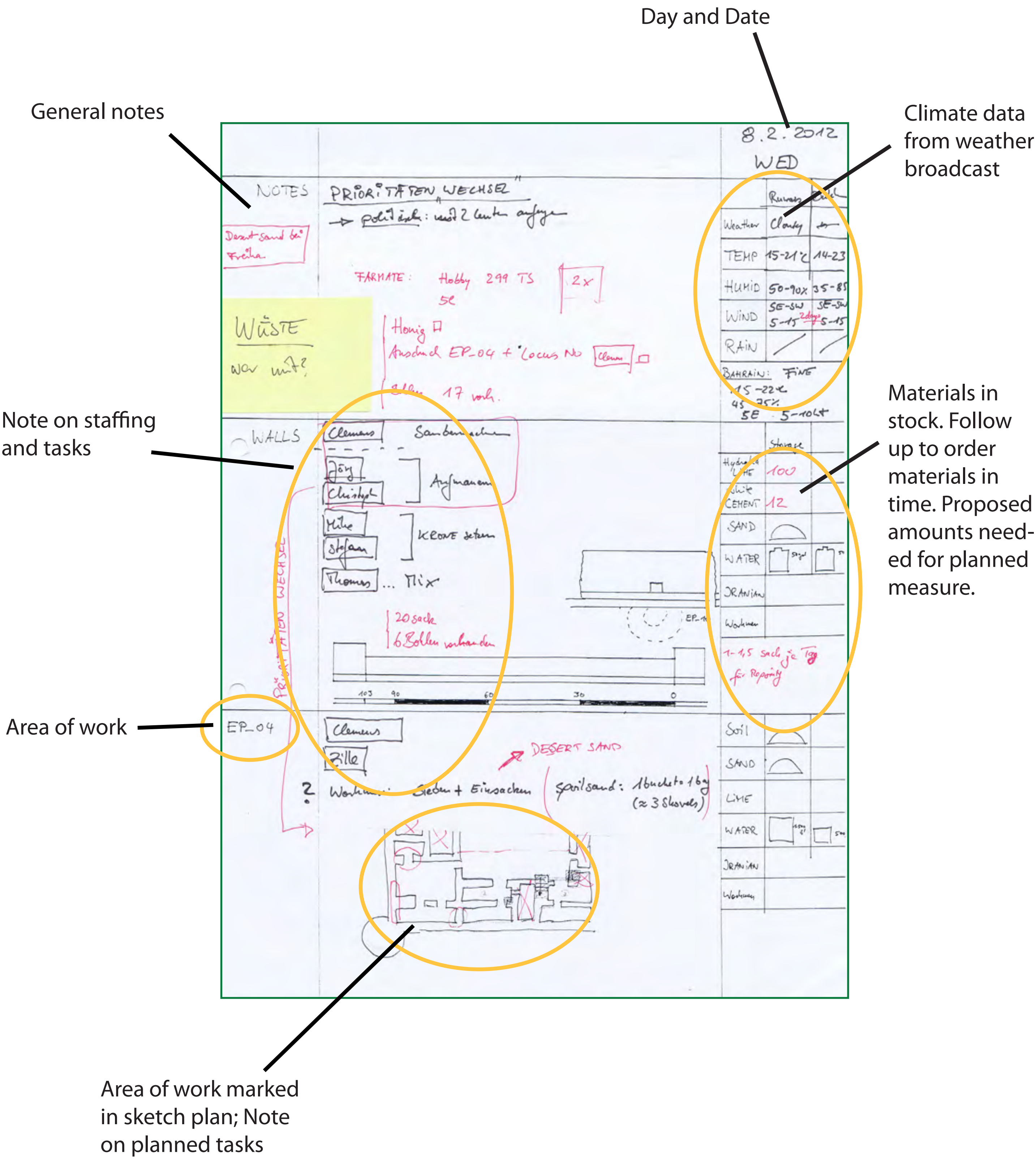



Reference: APPENDIX 9.4

FICHE No.6.3

# MONITORING

## Site journal - Examples from 2012




Reference: APPENDIX 9.4

## FICHE No.6.4

# MONITORING

## INDICATORS and PERIODICITY

### defined in AZAS-Management Plan

| Indicator | Periodicity | Location of Records |
|---|---|---|
| **Environmental parameters in Al Zubarah (Temperature, humidity, rain, wind)** | Daily records (Data Logger) Record should be downloaded regular after 3 to 6 months | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **Natural changes in north-western Qatar especially within the Buffer Zone (satellite pictures – landscape scale)** | Once a year /every second year or by notice | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **Infrastructural changes in north-western Qatar (Zubarah Hinterland) especially within the Buffer Zone** | Once a year /every second year, or by notice | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **No. of visitors (of the Visitors Centre)** | Daily record (by Guards at the Site entrance and/or at Al Zubarah Fort, for template see Conservation Handbook Appenix 9.1 ) | Handed in monthly in double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **Visitor experience (quality assessment of a visit to Al Zubarah)** | Once or twice a year | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **State of conservation in earlier QMA excavation areas (Photos, drawings, reports, 3D-scanning, etc.)** | Once a year or every third year (according to interval recommendation in last monitoring). For Inventory categories and record sheets see Conservation Handbook Fiche 6 (6.1 to 6.4) and Appendixes 9 & 10 | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH); Digital Inventory data base |
| **State of conservation in new QIAH excavation areas (Photos, drawings, reports, 3D-scanning, etc.)** | Once a year or every third year (according to interval recommendation in last monitoring). For Inventory categories and record sheets see Conservation Handbook Fiche 6 (6.1 to 6.4) and Appendixes 9 & 10 | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH); Digital Inventory data base |
| **State of conservation of not excavated structures (Photos, drawings, reports, 3D-scanning, etc.)** | General report every third year (according to interval recommendation in last monitoring). For Inventory categories and record sheets see Conservation Handbook Fiche 6 (6.1 to 6.4) and Appendix 9 & 10. | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH); Digital Inventory data base |
| **Damages caused by visitors** | Daily, weekly or monthly report (check particularly after the weekends) see Template Appendix 9.2 | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **Damages caused by high tides** | after observed high tides and each third year | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **Damages caused by heavy rain** | after (observed) heavy rainfalls | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| **Damages to infrastructure (walkways, panels, etc.)** | Daily, weekly and monthly reports (by Guards and on-site personnel). Check daily by guards. Report only when damages appear! For Report use Template in Conservation Handbook Appendix 9.2 | Double copy to be kept at the QMA and Site Management Office (until 2019 with the QIAH) |
| | | |

Reference: ASAZ Management Plan, December 2011: Chapter 11, p.71 - 75.

PART 4

# APPENDIXES

## TO CONSERVATION HANDBOOK
## for Al Zubarah Archaeological Site

4

QATAR ISLAMIC ARCHAEOLOGY AND HERITAGE PROJECT
مشروع قطر لعلم الآثار و التراث الإسلامي
Heritage | Archaeology | History | Environment

# LIST OF APPENDIXES




**Conservation Handbook for Al Zubarah Archaeological Site - PART 4**
Edited by Moritz Kinzel with contributions by Simone Ricca, Paul Hofmann and Robert Sobott.
First Edition January 2013 QIAH-01-02-HE-1000. DOHA /COPENHAGEN 2013
ISBN 978-87-89221-08-3

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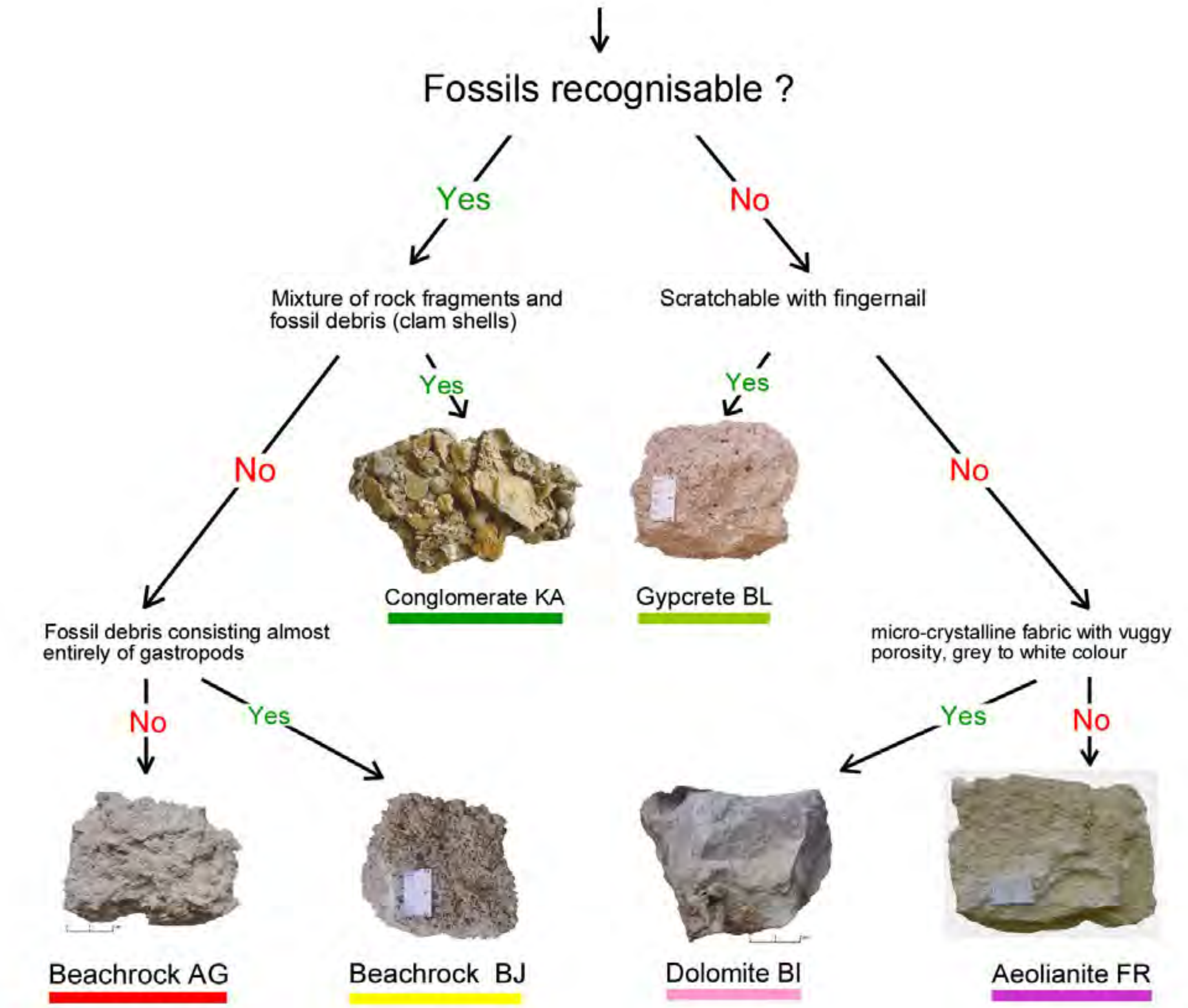
# APPENDIX 1
# CLASSIFICATION OF BUILDING STONES
## AT AL ZUBARAH / QATAR

R. Sobott, M.Kinzel and P. Hofmann
March 2011, revised version December 2012

# NOTES

# IDENTIFICATION SCHEME FOR BUILDING STONES ATTESTED AT AL ZUBARAH
## with colour code for mapping



**Classification of building stones**
**Sobott/Kinzel/Hofmann**

**Petrographic type :** **Beachrock (mollusc grain- to rudstone)**

**Code :** **AG**

**Varieties:** **AG 1, AG 2, AG 3**

**Mapping colour**

## Characteristic features

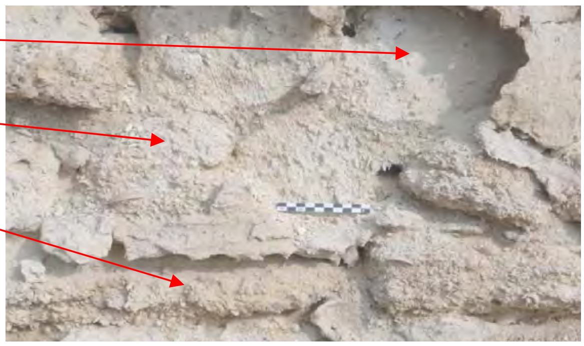
| | |
|---|---|
| General description: | friable, variably cemented assemblage of clams (mostly pelecypods) in a silty carbonate sand matrix; non-carbonate particles include quartz and feldspar grains; very low compressive strength; very porous fabric; from variety AG 1 to AG 3 the clam content decreases and the strength increases |
| Colour: | light yellow grey to whitish |
| Petrophysical properties: | porosity: 30-40 Vol.%, bulk density: ~1,55 g/cm3, ultrasonic velocity: 2,6 km/s |
| Weathering characteristics: | disintegrates to carbonate sand and clams which pile up at the base of walls |
| Bedding: | weakly indicated by orientation of clams in the matrix |
| Occurrence in wall structures: | most frequently used building-stone in the wall structures of Al Zubarah |

## Appearance in wall structure

AG 1

AG 2

AG 3

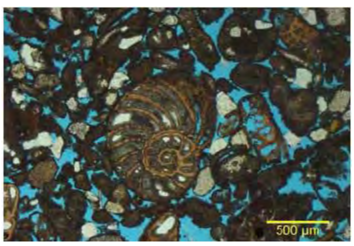


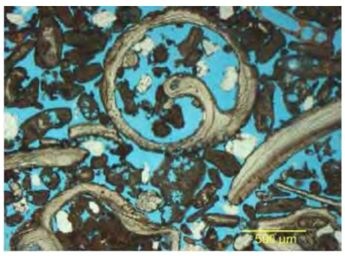
## Mineral composition +)

Magnesium calcite I
Magnesium calcite II
Aragonite
Dolomite
Quartz
Feldspars
(Halite)

+) determined by X-ray diffraction and thin section microscopy

## Thin section photographs (pore space is coloured blue)



**Classification of building stones**
**Sobott/Kinzel/Hofmann**

**Petrographic type :** **Beachrock (gastropod grain- to rudstone)**

**Code :** **BJ**

**Varieties:** **BJ 1, BJ 2, BJ 3**

**Mapping colour**

## Characteristic features

General description: friable interstratification of variably thick gastropod rich beds and carbonate sand beds; non-carbonate particles include quartz and feldspar grains; low compressive strength; very porous fabric; BJ 1 and BJ 3 are more or less thick gastropod rich or carbonate sand beds, respectively; BJ 2 is an interstratification of gastropod rich and carbonate sand beds

Colour: yellow grey; gastropod rich beds are a little bit darker than carbonate sand beds

Petrophysical properties: porosity: ~30 Vol.%, bulk density: ~1,56 g/cm3, ultrasonic velocity: 3,8 km/s

Weathering characteristics: disintegrates to carbonate sand and gastropods which pile up at the base of walls

Bedding: not recognisable in BJ 1, weak in BJ 3, and distinct in BJ 2

Occurrence in wall structures: generally less frequent than AG, but locally abundant

## Appearance in wall structure

BJ 1

BJ 2

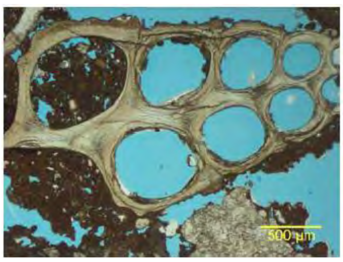
BJ 3

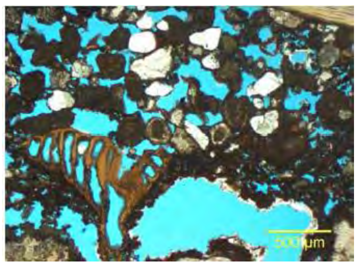
## Mineral composition +)

Magnesium calcite I
Magnesium calcite II
Aragonite
Dolomite
Quartz
Feldspars
(Halite)

+) determined by X-ray diffraction and thin section microscopy

## Thin section photographs (pore space is coloured blue)



**Classification of building stones**
**Sobott/Kinzel/Hofmann**

**Petrographic type :** **Peloidal grainstone (Aeolianite)**

**Code :** **FR**

**Varieties:**

**Mapping colour**

## Characteristic features

| | |
|---|---|
| General description: | grain-supported, very porous fabric of biogenic detritus (forams, bryozoa, peloids) Cemented by granular calcite; homogeneous particle size distribution; maximum at 200 µm, medium compressive strength |
| Colour: | light yellow |
| Petrophysical properties: | porosity: ~40 Vol.%, bulk density: ~1,63 g/cm3, ultrasonic velocity: 3,1 km/s |
| Weathering characteristics: | good weathering resistance, best building stone of the Al Zubarah area |
| Bedding: | hardly recognisable |
| Occurrence in wall structures: | preferably in more important buildings, e. g. in walls of mosques; more frequent in Freiha than in Al Zubarah, because of greater proximity to the quarries |

## Appearance in wall structure

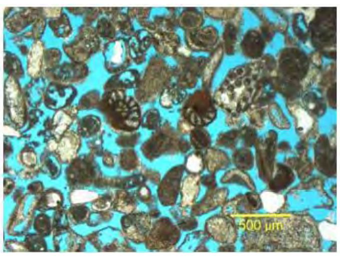
FR

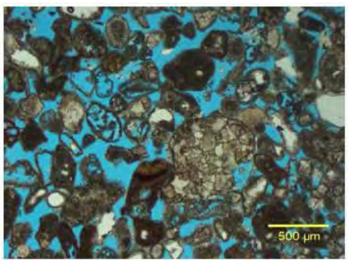
## Mineral composition [+)]

Calcite
Dolomite
Plagioclase
Quartz
Mg calcite II

[+)] determined by X-ray diffraction and thin section microscopy

## Thin section photographs (pore space is coloured blue)



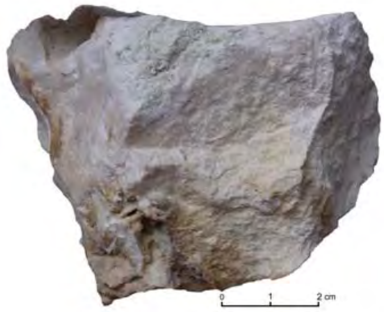
**Classification of building stones**
**Sobott/Kinzel/Hofmann**

**Petrographic type :** **Dolomite**

**Code :** **BL**

**Varieties:**

**Mapping colour**




## Characteristic features

| | |
|---|---|
| General description: | microcrystalline fabric of dolomite crystals; contains vugs which range in size from less than a millimetre to several centimetres; very high compressive strength due to dense fabric of interlocked dolomite crystals; no visible porosity |
| Colour: | grey to white with yellowish tint |
| Petrophysical properties: | porosity: <10 Vol.%, bulk density: 2,55 g/cm$^3$, ultrasonic velocity: 4,9 km/s |
| Weathering characteristics: | very good weathering resistance |
| Bedding: | not existent |
| Occurrence in wall structures: | seldomly used in original masonry; more frequent in repair work |

## Appearance in wall structure

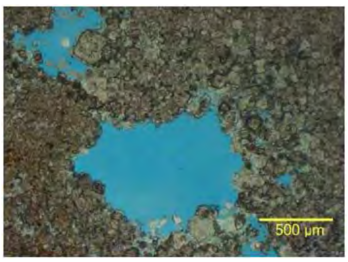
BL

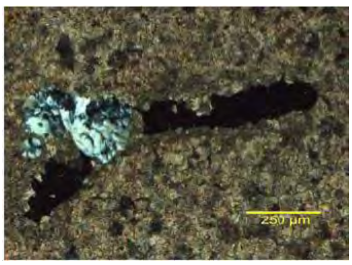
## Mineral composition +)

Dolomite
Quartz

+) determined by X-ray diffraction and thin section microscopy

## Thin section photographs (pore space is coloured blue)



**Classification of building stones**
**Sobott/Kinzel/Hofmann**

**Petrographic type :** **Conglomerate**

**Code :** **KA**

**Varieties:**

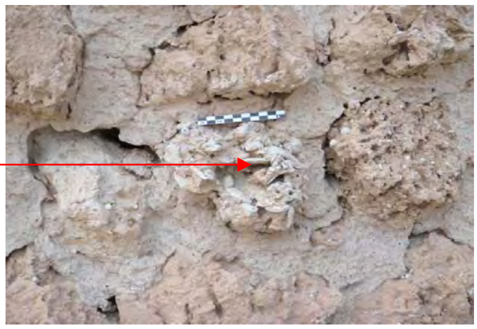
**Mapping colour**

## Characteristic features

| | |
|---|---|
| General description: | mixture of dolomite fragments and fossil debris (bivalves and gastropods) on a well cemented basal layer |
| Colour: | yellow grey |
| Petrophysical properties: | |
| Weathering characteristics: | good resistance to weathering due to good cementation of components |
| Bedding: | clearly marked by basal layer; rarely more than 2 or 3 layers |
| Occurrence in wall structures: | locally abundant |

## Appearance in wall structure

KA



| **Mineral composition** +) | **Thin section photographs** (pore space is coloured blue) | |
|---|---|---|
| Dolomite<br>Mg calcite<br>Aragonite<br>Calcite<br>Quartz<br><br>+) determined by X-ray diffraction and thin section microscopy | | |

**Classification of building stones**
**Sobott/Kinzel/Hofmann**

| | |
|---|---|
| **Petrographic type :** | **Gypcrete** (evaporitic mudstone with rock fragments) |
| **Code :** | **BE** |
| **Varieties:** | |

**Mapping colour**

## Characteristic features

| | |
|---|---|
| General description: | porous crypto-crystalline gypsum matrix with rock and mineral fragments and little fossil debris; low compressive strength due to the porous structure and low hardness of gypsum |
| Colour: | light yellow grey to white |
| Petrophysical properties: | porosity: ~39 Vol.%, bulk density: 1,5 g/cm$^3$, ultrasonic velocity: 2,5 km/s |
| Weathering characteristics: | good weathering resistance |
| Bedding: | not recognisable |
| Occurrence in wall structures: | less frequent |

## Appearance in wall structure

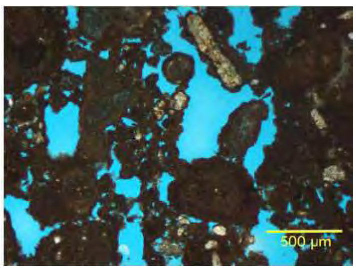
BE

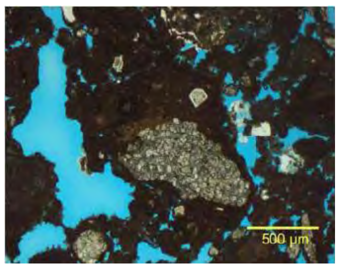
## Mineral composition +)

Gypsum
Dolomite
Mg calcite
Aragonite
Quartz
Feldpar

+) determined by X-ray diffraction and thin section microscopy

## Thin section photographs (pore space is coloured blue)



# APPENDIX 2

# MORTARS & PLASTERS TESTED

## AT AL ZUBARAH / QATAR

P. Hofmann & R. Sobott

March 2012

Angelegte Probeflächen ab Juni 2010

**1. Mörtel**

| Identifikation | | | | | | Untergrund | | | Mörtelmischung | Bindemittel | | | | | Zuschlag | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Probe-Nr. | Monat/Jahr Probe | Art der Anwendung | Anwendungsort | Wand/Lokus | Ausrichtung | dominierender Stein | durchschnittl. Zustand 1=lose -5= sehr fest | Bemerkung | Mörtel-Nr. | hK (RT) | Wkh (RT) | An (RT) | Wzm (RT) | sPz (RT) | Qs (RT) | Soil/dessert-sand (RT) | Mks (RT) | Ty (%) | Mischungsverhältnis Bindemittel/Zuschläge | Pig (%) | Bemerkung |
| | 2009 | | | | | | | | | | | | | | | | | | | | |
| 1.1 | 11.09 | Fu | QMA2 | T112 | E | AG, BJ | 1-3 | | | | | | | | | *Soil | | | | | soil morter, anstehender Boden, obere Salzschicht entfernt, alle Korngrößen mit Wasser angerührt |
| | 2010 | | | | | | | | | | | | | | | | | | | | |
| 1.2 | 06.10 | MW | QMA2 | T112 | | | | Aufmauerung mit FR | II | 1 | | | | | 3 | | | | 1:3 | | hK-NHL5 |
| 1.3 | 06.10 | MW | QMA2 | T112 | | | | Aufmauerung mit FR | III | | | 1 | | | 3 | | | | 1:3 | | An-durch QMA zur Verfügung gestellt |
| 1.4 | 06.10 | Fu | QMA2 | T112 | E | (FR) | (4-5) | teilweise auf Mw mit M-Nr.III aus 06.11 | X | | | 3 | | | 2 | | 4 | | 1:2 | | An-durch QMA zur Verfügung gestellt |
| 1.5 | 06.10 | Fu | QMA2 | T112 | E | FR | 4-5 | auf Mw mit M-Nr.III aus 06.11 | XI | 3 | | | | | 3 | | 6 | ~1 masse | 1:3 | | hK-NHL5 |
| 1.6 | 06.10 | Fu | QMA2 | T112 | E | FR | 4-5 | auf Mw mit M-Nr.II aus 06.11 | XI | 3RT | | | | | 3RT | | 6RT | ~1 masse | 1:3 | | hK-NHL5 |
| 1.7 | 06.10 | Fu | QMA2 | T112 | NE | FR | 4 | | IV | | | 1 | | | 2 | | | | 1:2 | | An-durch QMA zur Verfügung gestellt |
| 1.8 | 06.10 | Fu | QMA2 | T112 | N | FR,BJ | 3-4 | | VI | | | 2 | | | 2 | | 4 | ~2 masse | 1:3 | | An-durch QMA zur Verfügung gestellt |
| 1.9 | 06.10 | Fu | QMA2 | T112 | N | FR | 4-5 | | VIII | 3 | | | | | 3 | | 6 | ~2 masse | 1:3 | | hK-NHL5 |
| 1.10 | 06.10 | Sch | QMA2 | T112 | S | AG | 1-2 | | XII | 1 | | | | | 1 | | | ~1 masse | 1:1 | | hK-NHL5 |
| 1.11 | 06.10 | Sch | QMA2 | T112 | W | BJ | 2-3 | | VII | 3 | | | | | 3 | | 6 | ~2 masse | 1:3 | | hK-NHL5 |
| 1.12 | 06.10 | Fu | QMA2 | T112 | W | BJ | 2-3 | | IX | | | 1 | | | 2 | | | | 1:2 | | An-durch QMA zur Verfügung gestellt |
| 1.13 | 06.10 | Sch | QMA2 | T112 | W | BJ | 2-3 | | XIII | 1 | | | | | 1 | | | ~1 masse | 1:1 | | hK-NHL5 |
| | 2011 | | | | | | | | | | | | | | | | | | | | |
| 1.14 | 02.11 | Mw | T8 | | N | | | Aufmauerung mit LA/KA und BL im Fundamentbereich, darüber mit LO | II | 1 | | | | | 3 | | | | 1:3 | | hK-NHL5 |
| 1.15 | 02.11 | Sch | T8 | | N | LO | 4-5 | auf Mw und Fu mit M-Nr.II aus 02.11 | XIV | 1 | | | | | 4 | | 2 | ~0,4 masse | 1:6 | ~0,1% Ocker rot ~0,1% Ocker gelb | hK-NHL5 |
| 1.16 | 02.11 | Fu | T8 | | N | LO | 4-5 | | II | 1 | | | | | 3 | | | | 1:3 | | hK-NHL5 |
| 1.17 | 02.11 | Fu | T8 | | NNE | LO | 4-5 | | XV | 2 | | | | | 3 | | 3 | | 1:3 | | hK-NHL5 |

| | Verarbeitung | | | | | | Begutachtung -visuell | | | | | | | Begutachtung Labor | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Probe-Nr. | Standzeit Mischung | Verarbeitbarkeit 1=schwer - 5=sehr gut | Auftragsstärke in mm | Haftung 1=schlecht - 5=sehr gut | Schwundrisse 1=viel - 5=keine | Primärfarbe (trocken) | Monat/Jahr | Festigkeit 1=schlecht - 5=sehr gut | Haftung 1=schlecht - 5=sehr gut | Absanden 1=viel - 5=kein | Risse 1=viele - 5=keine | Sekundärfarbe | Bemerkung | Datum Analyse | Festigkeit in N/qmm | | Bewertung |
| 1.1 | 3h | 5 | | 3 | 5 | Erdfarben | 10.11 | 2 | 2 | 1-2 | 5 | Sandfarbe | ca. 80% Verlust des Mörtels | | | | bedingt verwendbar, Mörtel darf nicht der Bewitterung ausgesetzt werden, Problem der Anhaftung von Pu oder Sch |
| 1.2 | 3h | 5 | | 4-5 | 4 | hell beige | 10.11 | 4 | 4 | 4 | 4 | beige | | | | | verwendbar |
| 1.3 | 15 min | 4 | | 4 | 4-5 | sehr hell beige | 10.11 | 1 | 1 | 1 | 5 | Sandfarbe | | | | | nicht verwendbar |
| 1.4 | 15 min | 2 | | 4-5 | 4-5 | sehr hell beige | 10.11 | 1 | 1 | 1 | | hell beige | ca. 90% Verlust des Mörtels | | | | nicht verwendbar |
| 1.5 | 3h | 3-4 | | 4-5 | 3 | hell beige | 10.11 | 2-3 | 2-3 | 2 | 3 | hell beige | | | | | verwendbar, möglicherweise Ty-Anteil zu hoch, seine Festigkeit ist abhängig vom Untergrund |
| 1.6 | 3h | 3-4 | | 4-5 | 3 | hell beige | 10.11 | 4 | 4 | 4-5 | 3 | hell beige | | | | | verwendbar, möglicherweise Ty-Anteil zu hoch, seine Festigkeit ist abhängig vom Untergrund |
| 1.7 | 15 min | 4 | | 4-5 | 4-5 | sehr hell beige | 10.11 | 3 | 3-4 | 2 | 4-5 | Sandfarbe | nach Absanden fast weiß | | | | bedingt verwendbar, möglichwerweise unter Verwendung von frischem An-Mörtel |
| 1.8 | 15 min | 1 | | 4-5 | 4-5 | sehr hell beige | 10.11 | 3 | 4 | 2-3 | 4-5 | hell beige | | | | | bedingt verwendbar, Bindung offensichtlich durch hohen Ty-Anteil hergestellt |
| 1.9 | 3h | 2 | | 4-5 | 3 | hell beige | 10.11 | 4-5 | 4 | 4 | 4-5 | beige | | | | | verwendbar, Verarbeitung wegen Ty-Anteilund Mks schwierig |
| 1.10 | 1h | 2-3 | 3-20 | 2-3 | 3 | hell beige | 10.11 | | | | | | ca. 95% Verlust des Mörtels | | | | auf vorgegebenem Untergrund nicht verwendbar |
| 1.11 | 3h | 3 | 3-20 | 2-3 | 2-3 | hell beige | 10.11 | 2 | 2-3 | 2 | 4 | beige | | | | | bedingt verwendbar, abhängig vom Untergrund (Haftung) |
| 1.12 | 15 min | 3 | | 4 | 4-5 | sehr hell beige | 10.11 | | | | | | ca. 98% Verlust des Mörtels | | | | nicht verwendbar |
| 1.13 | 3h | 3 | 3-20 | 3 | 3 | hell beige | 10.11 | 3-4 | 3-4 | 3-4 | 4-5 | hell beige | | | | | bedingt verwendbar, abhängig vom Untergrund (Haftung) |
| 1.14 | 3h | 5 | | 4 | 4-5 | hell beige | 10.11 | 4 | 4 | 4 | 4 | beige | | | | | verwendbar |
| 1.15 | 1h | 3-4 | 2-20 | 4-5 | 4 | rötlich beige | 10.11 | 4 | 4-5 | 3-4 | 5 | hell beige | | | | | verwendbar |
| 1.16 | 3h | 5 | | 4-5 | 4-5 | hell beige | 10.11 | 4 | 4 | 3-4 | 3-4 | beige | | | | | verwendbar |
| 1.17 | 3h | 3 | | 4-5 | 4 | hell beige | 10.11 | 4 | 4 | 4 | 3-4 | hell beige | | | | | verwendbar |

Angelegte Probeflächen ab Juni 2010

**1. Mörtel**

| Identifikation: Probe-Nr. | Monat/Jahr Probe | Art der Anwendung | Anwendungsort | Wand/Lokus | Ausrichtung | Untergrund: dominierender Stein | durchschnittl. Zustand 1=lose -5= sehr fest | Bemerkung | Mörtelmischung: Mörtel-Nr. | Bindemittel: hK (RT) | Wkh (RT) | An (RT) | Wzm (RT) | sPz (RT) | Zuschlag: Qs (RT) | Soil/dessert-sand (RT) | Mks (RT) | Ty (%) | Mischungsverhältnis Bindemittel/Zuschläge | Pig (%) | Bemerkung |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2009 | | | | | | | | | | | | | | | | | | | | |
| 1.1 | 11.09 | Fu | QMA2 | T112 | E | AG, BJ | 1-3 | | | | | | | | | *Soil | | | | | soil morter, anstehender Boden, obere Salzschicht entfernt, alle Korngrößen mit Wasser angerührt |
| | 2010 | | | | | | | | | | | | | | | | | | | | |
| 1.2 | 06.10 | MW | QMA2 | T112 | | | | Aufmauerung mit FR | II | 1 | | | | | 3 | | | | 1:3 | | hK-NHL5 |
| 1.3 | 06.10 | MW | QMA2 | T112 | | | | Aufmauerung mit FR | III | | | 1 | | | 3 | | | | 1:3 | | An-durch QMA zur Verfügung gestellt |
| 1.4 | 06.10 | Fu | QMA2 | T112 | E | (FR) | (4-5) | teilweise auf Mw mit M-Nr.III aus 06.11 | X | | | 3 | | | 2 | | 4 | | 1:2 | | An-durch QMA zur Verfügung gestellt |
| 1.5 | 06.10 | Fu | QMA2 | T112 | E | FR | 4-5 | auf Mw mit M-Nr.III aus 06.11 | XI | 3 | | | | | 3 | | 6 | ~1 masse | 1:3 | | hK-NHL5 |
| 1.6 | 06.10 | Fu | QMA2 | T112 | E | FR | 4-5 | auf Mw mit M-Nr.II aus 06.11 | XI | 3RT | | | | | 3RT | | 6RT | ~1 masse | 1:3 | | hK-NHL5 |
| 1.7 | 06.10 | Fu | QMA2 | T112 | NE | FR | 4 | | IV | | | 1 | | | 2 | | | | 1:2 | | An-durch QMA zur Verfügung gestellt |
| 1.8 | 06.10 | Fu | QMA2 | T112 | N | FR,BJ | 3-4 | | VI | | | 2 | | | 2 | | 4 | ~2 masse | 1:3 | | An-durch QMA zur Verfügung gestellt |
| 1.9 | 06.10 | Fu | QMA2 | T112 | N | FR | 4-5 | | VIII | 3 | | | | | 3 | | 6 | ~2 masse | 1:3 | | hK-NHL5 |
| 1.10 | 06.10 | Sch | QMA2 | T112 | S | AG | 1-2 | | XII | 1 | | | | | 1 | | | ~1 masse | 1:1 | | hK-NHL5 |
| 1.11 | 06.10 | Sch | QMA2 | T112 | W | BJ | 2-3 | | VII | 3 | | | | | 3 | | 6 | ~2 masse | 1:3 | | hK-NHL5 |
| 1.12 | 06.10 | Fu | QMA2 | T112 | W | BJ | 2-3 | | IX | | | 1 | | | 2 | | | | 1:2 | | An-durch QMA zur Verfügung gestellt |
| 1.13 | 06.10 | Sch | QMA2 | T112 | W | BJ | 2-3 | | XIII | 1 | | | | | 1 | | | ~1 masse | 1:1 | | hK-NHL5 |
| | 2011 | | | | | | | | | | | | | | | | | | | | |
| 1.14 | 02.11 | Mw | T8 | | N | | | Aufmauerung mit LA/KA und BL im Fundamentbereich, darüber mit LO | II | 1 | | | | | 3 | | | | 1:3 | | hK-NHL5 |
| 1.15 | 02.11 | Sch | T8 | | N | LO | 4-5 | auf Mw und Fu mit M-Nr.II aus 02.11 | XIV | 1 | | | | | 4 | | 2 | ~0,4 masse | 1:6 | ~0,1% Ocker rot ~0,1% Ocker gelb | hK-NHL5 |
| 1.16 | 02.11 | Fu | T8 | | N | LO | 4-5 | | II | 1 | | | | | 3 | | | | 1:3 | | hK-NHL5 |
| 1.17 | 02.11 | Fu | T8 | | NNE | LO | 4-5 | | XV | 2 | | | | | 3 | | 3 | | 1:3 | | hK-NHL5 |

| Probe-Nr. | Verarbeitung: Standzeit Mischung | Verarbeitbarkeit 1=schwer - 5=sehr gut | Auftragsstärke in mm | Haftung 1=schlecht - 5=sehr gut | Schwundrisse 1=viel - 5=keine | Primärfarbe (trocken) | Begutachtung -visuell: Monat/Jahr | Festigkeit 1=schlecht - 5=sehr gut | Haftung 1=schlecht - 5=sehr gut | Absanden 1=viel - 5=kein | Risse 1=viele - 5=keine | Sekundärfarbe | Bemerkung | Begutachtung Labor: Datum Analyse | Festigkeit in N/qmm | Bewertung |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | 3h | 5 | | 3 | 5 | Erdfarben | 10.11 | 2 | 2 | 1-2 | 5 | Sandfarbe | ca. 80% Verlust des Mörtels | | | bedingt verwendbar, Mörtel darf nicht der Bewitterung ausgesetzt werden, Problem der Anhaftung von Pu oder Sch |
| 1.2 | 3h | 5 | | 4-5 | 4 | hell beige | 10.11 | 4 | 4 | 4 | 4 | beige | | | | verwendbar |
| 1.3 | 15 min | 4 | | 4 | 4-5 | sehr hell beige | 10.11 | 1 | 1 | 1 | 5 | Sandfarbe | | | | nicht verwendbar |
| 1.4 | 15 min | 2 | | 4-5 | 4-5 | sehr hell beige | 10.11 | 1 | 1 | 1 | | hell beige | ca. 90% Verlust des Mörtels | | | nicht verwendbar |
| 1.5 | 3h | 3-4 | | 4-5 | 3 | hell beige | 10.11 | 2-3 | 2-3 | 2 | 3 | hell beige | | | | verwendbar, möglicherweise Ty-Anteil zu hoch, seine Festigkeit ist abhängig vom Untergrund |
| 1.6 | 3h | 3-4 | | 4-5 | 3 | hell beige | 10.11 | 4 | 4 | 4-5 | 3 | hell beige | | | | verwendbar, möglicherweise Ty-Anteil zu hoch, seine Festigkeit ist abhängig vom Untergrund |
| 1.7 | 15 min | 4 | | 4-5 | 4-5 | sehr hell beige | 10.11 | 3 | 3-4 | 2 | 4-5 | Sandfarbe | nach Absanden fast weiß | | | bedingt verwendbar, möglichwerweise unter Verwendung von frischem An-Mörtel |
| 1.8 | 15 min | 1 | | 4-5 | 4-5 | sehr hell beige | 10.11 | 3 | 4 | 2-3 | 4-5 | hell beige | | | | bedingt verwendbar, Bindung offensichtlich durch hohen Ty-Anteil hergestellt |
| 1.9 | 3h | 2 | | 4-5 | 3 | hell beige | 10.11 | 4-5 | 4 | 4 | 4-5 | beige | | | | verwendbar, Verarbeitung wegen Ty-Anteilund Mks schwierig |
| 1.10 | 1h | 2-3 | 3-20 | 2-3 | 3 | hell beige | 10.11 | | | | | | ca. 95% Verlust des Mörtels | | | auf vorgegebenem Untergrund nicht verwendbar |
| 1.11 | 3h | 3 | 3-20 | 2-3 | 2-3 | hell beige | 10.11 | 2 | 2-3 | 2 | 4 | beige | | | | bedingt verwendbar, abhängig vom Untergrund (Haftung) |
| 1.12 | 15 min | 3 | | 4 | 4-5 | sehr hell beige | 10.11 | | | | | | ca. 98% Verlust des Mörtels | | | nicht verwendbar |
| 1.13 | 3h | 3 | 3-20 | 3 | 3 | hell beige | 10.11 | 3-4 | 3-4 | 3-4 | 4-5 | hell beige | | | | bedingt verwendbar, abhängig vom Untergrund (Haftung) |
| 1.14 | 3h | 5 | | 4 | 4-5 | hell beige | 10.11 | 4 | 4 | 4 | 4 | beige | | | | verwendbar |
| 1.15 | 1h | 3-4 | 2-20 | 4-5 | 4 | rötlich beige | 10.11 | 4 | 4-5 | 3-4 | 5 | hell beige | | | | verwendbar |
| 1.16 | 3h | 5 | | 4-5 | 4-5 | hell beige | 10.11 | 4 | 4 | 3-4 | 3-4 | beige | | | | verwendbar |
| 1.17 | 3h | 3 | | 4-5 | 4 | hell beige | 10.11 | 4 | 4 | 4 | 3-4 | hell beige | | | | verwendbar |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.18 | 02.11 | Fu | T8 | | NE | LO | 4-5 | | XVI | 2 | | | | | 3 | | 3 | ~0,2 masse | 1:3 | | hK-NHL5 | 3h | 2-3 | 4-5 | 4-5 | 3 | hell beige | 10.11 | 4 | 4 | 4 | 3 | hell beige | | | | | verwendbar |
| 1.19 | 02.11 | Sch | T8 | | E | LO | 4-5 | | XVI | 2 | | | | | 3 | | 3 | ~0,2 masse | 1:3 | | hK-NHL5 | 3h | 2 | 10-30 | 4-5 | 3 | hell beige | 10.11 | 4 | 4 | 4 | 3 | hell beige | | | | | verwendbar |
| 1.20 | 02.11 | Sch | T8 | | E | LO | 4-5 | auf teilweise Mw und Fu mit M-Nr.II aus 02.11 | IIa | 1 | | | | | 3 | | | ~0,1 masse | 1:3 | | hK-NHL5 | 3h | 4 | 10-30 | 4-5 | 4 | hell beige | 10.11 | 4 | 4 | 3-4 | 3 | beige | | | | | verwendbar |
| 1.21 | 02.11 | Sch | T8 | | SE | LO | 4-5 | auf Fu mit M-Nr.II aus 02.11 | XVII | 1 | | 4 | | | 10 | | | ~0,1 masse | 1:2 | | hK-NHL5,An-durch QMA zur Verfügung gestellt | 15 min | 1-2 | 4-5 | 4-5 | 4 | hellgrau bis weiß | 10.11 | 4-5 | 4 | 3-4 | 3 | hellgrau | | | | | bedingt verwendbar, problematisch scheint für den An der Untergrund zu sein, benötigt gute Haftung, salzfrei und trockenen Untergrund |
| 1.22 | 02.11 | Sch | T8 | | ESE | LO | 4-5 | auf Mw und Fu mit M-Nr.II aus 02.11, im unteren Teil MW noch naß bei Auftrag | XVIII | 1 | | 4 | | | 6 | | | ~0,1 masse | 5:6 | | hK-NHL5,An-durch QMA zur Verfügung gestellt | 15 min | 1-2 | 4-5 | 4-5 | 4 | hellgrau | 10.11 | 4-5/1 | 4/1 | 3-4/1 | 3 | hellgrau | im Bereich der frischen Aufmauerung löst sich Mö komplett auf, völliger Bindungsverlust | | | | bedingt verwendbar, problematisch scheint für den An der Untergrund zu sein, benötigt gute Haftung, salzfrei und trockenen Untergrund |
| 1.23 | 03.11 | VSch | EP04 | Loc.4010 Wand außen | S | AG,BJ | 1-2 | | | 1% in H2O | | | | | | | | ~0,1% in H2O | | | hK-NHL5, die VSch soll die Haftung auf schwierigem Untergrund verbessern | 1h | 4 | 0-2 | 1-3 | 3 | hell beige | | | | | | | extreme Unterschiede, Kristallisationszone sehr fest mit z.T. starken Verkrustungen, zur Krone hin Festigkeit abnehmend, hier stärker absandend, Festigkeitsprofil spiegelt sich auch in den Farben wider,von hell beige bis braun beige, offensichtlich Haftung in Abhängigkeit vom Untergrund und Kristallisationszyklen | | | | inwieweit die VSch die Haftung tatsächlich verbessert ist noch nicht ganz klar |
| | | Sch | | | | | | | II | 1 | | | | | 3 | | | | 1:3 | | | 3h | 4 | 10-100 | | | | 10.11 | 2-5 | 1-5 | 3-5 | 4 | beige* | | | | | möglicherweise nach Verbesserung der Rezeptur besser verwendbar |
| 1.24 | 03.11 | VSch | EP04 | Loc.4010 Wand innen | N | AG,BJ | 1-2 | | | 1% in H2O | | | | | | | | ~0,1% in H2O | | | hK-NHL5, die VSch soll die Haftung auf schwierigem Untergrund verbessern | 1h | 4 | 0-2 | 1-3 | 3 | hell beige | | | | | | | gleichmäßiger Charakter, weniger absandend, weniger Farbunterschiede, offensichtlich Haftung in Abhängigkeit vom Untergrund und Kristallisationszyklen | | | | inwieweit die VSch die Haftung tatsächlich verbessert ist noch nicht ganz klar |
| | | Sch | | | | | | | IIa | 1 | | | | | 3 | | | ~0,1 masse | 1:3 | | | 3h | 3 | 10-100 | | | | 10.11 | 3-4 | 3-4 | 3-5 | 3-4 | beige | | | | | verwendbar, möglichweise kann die Veränderung des Ty-Anteils zu besseren Ergebnissen führen |
| 1.25 | 03.11 | Mw | Tw7-8 | Abdeckung Mauer | | | 4-5 | Untergrund neu hergestellt (03.11.) mit M-Nr.II, Abdeckung mit FR, in Platten gespalten, Test zur Ästhetik und verbesserten Wasserführung | II | 1 | | | | | 3 | | | | 1:3 | | hK-NHL5 | 3h | 4-5 | | 4 | 4-5 | hell beige | 10.11 | 4 | 4 | 4 | 4 | beige | | | | | verwendbar |
| 1.26 | 03.11 | Sch | T8 | rechts | W | AG | 3 | auf teilweise Mw und Fu mit M-Nr.II aus 02.11 | | | | 1 | | | 2 | | | | 1:2 | | An-Casuflor AB30 | 30 min. | 2-3 | 10-30 | 3 | 4-5 | weiß bis hellgrau | 10.11 | 3/1 | 2-3/1 | 2-3/1 | 3 | hellgrau | im unteren Teil starkes Absanden, deutlicher Substanzverlust, Auflösen der Bindung, Haftungsproblem, Salze | | | | nicht verwendbar |
| 1.27 | 03.11 | Sch | T8 | links | W | AG | 1-2 | auf teilweise Mw und Fu mit M-Nr.II aus 02.11 | | | | 1 | | | 2 | | | | 1:2 | | An-Casusan HAP | 30 min. | 2-3 | 10-30 | 3 | 4-5 | hellgrau | 10.11 | 2-3 | 2 | 1-2 | 3 | hell beige | im unteren Teil kompletter Mö-Verlust | | | | nicht verwendbar |
| 1.28 | 11.11. | Mw, Fu | QMA2, R101 | Wand E2 unten | S | BJ, FR, AG | 1-2 | Fu-Mörtel von ca. 1984 teilweise in Probefläche belassen. | XXIV | | 1 | | | | 4 | | | | 1:4 | | | 3h | 3 | >20 | 3 | 4-5 | sehr hell beige | | | | | | | | | | | |
| 1.29 | 11.11. | Mw | QMA2, R101 | Wand E2 oben | S | BJ, FR, AG | 1-2 | Fu-Mörtel von ca. 1984 teilweise in Probefläche belassen. | XXVII | | 1 | | | | 3 | | | | 1:3 | | | 3h | 3 | | 3-4 | 3-4 | sehr hell | | | | | | | | | | | |
| 1.30 | 11.11. | Mw | QMA2, R101 | Wand D3 | W | BJ, AG | 1-2 | | XXX | | 1 | | | | 2 | | | | 1:2 | | | 3h | 3-4 | >20 | 4 | 2 | sehr hell | | | | | | | | | | | |
| 1.31 | 11.11. | Mw, Fu | QMA2, R101 | Wand G2/F | N/ W | FR, LO | 4-5 | Maurermörtel zur statischen und strukturellen Sicherung, Steinaustausch, Vorbereitung OF für Putz | XXV | | 2,5 | | 0,5 | | 12 | | | | 1:4 | | Verwendung als Mauer- und Fugenmörtel in Stadtmauer zw. T8 und T9 in 11.2011-01.2012, ab 18.01.2012 siehe Probe 1.51 | 3h | 4-5 | >20 | 4 | 4 | sehr hell | | | | | | | | 01.12. | ~1,1 | | Labor empfiehlt die Erhöhung der Festigkeit, siehe 1.51, Verwendung 17.01.2012 eingestellt |
| 1.32 | 11.11. | Mw, Fu | QMA2, R101 | Wand B3 | E | BJ, AG | 2 | Fu-Mörtel von ca. 1984 teilweise in Probefläche belassen. | XXVI | | 2 | | 1 | | | 12 *Soil | | | 1:4 | | Soil gesiebt, Linie bis ca. 6 mm, gewonnen nahe T8 | 2h | 2 | | 2-3 | 4 | sandfarben hell | | | | | | | | 01.12. | ~3-4 | | |
| 1.33 | 11.11. | Mw | QMA2, R101 | Wand A1 | S | BJ, FR | 3-4 | | XXIII | | 4 | | | 1 | 10 | | | | 1:2 | | Fu-Mörtel nicht abgedeckt (bedeckter Himmel, hohe Luftfeuchte), MW-Probe rechte untere Ecke stehen gelassen | 3h | 4 | | 4 | 3-4 | hell lichtgrau | | | | | | | | | | | |
| | | Fu | | | | | | | XXV | | 2 | | 1 | | 12 | | | | 1:4 | | | 3h | 3-4 | 10-60 | 4 | 4 | sehr hell | | | | | | | | | | | |
| 1.34 | 11.11 | Mw | , R101 | d H1 | W | BJ, | 2 | | XXVIII | | 6 | | | 1 | 28 | | | | 1:4 | | Fu-Mörtel nicht abgedeckt (bedeckter Himmel, hohe Luftfeuchte) | 3h | 3 | | 3 | 4-5 | hell lichtgrau | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fu | QMA2 | Wan | | AG | | | XXV | | 2 | | 1 | | 12 | | | | 1:4 | | | 3h | 3-4 | 10-60 | 4 | 4 | sehr hell | | | | | | | | | | | |
| 1.35 | 11.11. | Mw | QMA2, R101 | Wand G1 | N | FR, AG | 4 | | XXI | | 3 | | | 1 | 8 | | | | 1:2 | | Fu-Mörtel nicht abgedeckt (bedeckter Himmel, hohe Luftfeuchte), MW-Probe rechte untere Ecke stehen gelassen | 3h | 4 | | 4 | 3-4 | hell grau | | | | | | | | | | | |
| | | Fu | | | | | | | XXV | | 2 | | 1 | | 12 | | | | 1:4 | | | 3h | 3-4 | 10-60 | 4 | 4 | sehr hell | | | | | | | | | | | |
| 1.36 | 11.11. | Mw | QMA2, R101 | Wand E1 | S | BJ, FR, AG | 3 | | XXII | | 3 | | | 1 | 12 | | | | 1:3 | | Fu-Mörtel nicht abgedeckt (bedeckter Himmel, hohe Luftfeuchte) | 3h | 4 | | 4 | 3-4 | hell grau | | | | | | | | | | | |
| | | Fu | | | | | | | XXV | | 2 | | 1 | | 12 | | | | 1:4 | | | 3h | 3-4 | 10-60 | 4 | 4 | sehr hell | | | | | | | | | | | |
| 1.37 | 11.11. | Mw | QMA2, R101 | Wand B2 | E | BJ, AG | 2 | Fu-Mörtel von ca. 1984 teilweise in Probefläche belassen. | XXVII | | | | | 1 | 1 | 3 *Soil | | | 1:4 | | soil morter, anstehender Boden, obere Salzschicht entfernt, alle Korngrößen mit Wasser angerührt, Fu-Mörtel nicht abgedeckt (bedeckter Himmel, hohe Luftfeuchte) | 2h | 2-3 | | 3 | 4 | grau | | | | | | | | | | | |
| | | Fu | | | | | | | XXV | | 2 | | 1 | | 12 | | | | 1:4 | | | 3h | 3-4 | 10-60 | 4 | 4 | sehr hell | | | | | | | | | | | |
| 1.38 | 11.11. | MW, Fu | QMA2, R101 | Wand B4 unten | E | BJ, AG | 2 | Fu-Mörtel von ca. 1984 teilweise in Probefläche belassen. | XXIX | | 1 | 3 | | | 8 | | | | 1:2 | | hK-NHL5,An-durch QMA zur Verfügung gestellt | 1h | 2 | 10-100 | 3-4 | 4-5 | sehr hellgrau | | | | | | | | | | | |
| 1.39 | 11.11. | Sch | T8 | unten | SE | LO | 4-5 | auf Mw und Fu mit M-Nr.II aus 02.11. | XXXII | | 3 | | 1 | | 16 | | | ~0,1 masse | 1:4 | | | 3h | 4 | 10-30 | 4 | 3 | sehr hell beige | | | | | | | | | | | |
| 1.40 | 11.11. | Sch | T8 | oben | SE | LO | 4-5 | auf Mw und Fu mit M-Nr.II aus 02.11. | XXXIIa | | 3 | | 1 | | 16 | | ~1,5% | ~0,1 masse | 1:4 | | | 3h | 4 | 10-30 | 4 | 3 | sehr hell beige | | | | | | | | | | | |
| 1.41 | 11.11. | Sch | T8 | unten | SSE | LO | 4-5 | auf Mw und Fu mit M-Nr.II aus 02.11. | XXXIII | | 3 | | 1 | | 12 | | | ~0,1 masse | 1:3 | | | 3h | 4 | 10-30 | 4 | 3 | sehr hell beige | | | | | | | | | | | |
| 1.42 | 11.11. | Sch | T8 | oben | SSE | LO | 4-5 | auf Mw und Fu mit M-Nr.II aus 02.11. | XXXIIIa | | 3 | | 1 | | 12 | | ~1,5% | ~0,1 masse | 1:3 | | | 3h | 4 | 10-30 | 4 | 3 | sehr hell beige | | | | | | | | | | | |
| 1.43 | 12.11. | Pu | QMA2, R101 | Wand B4 | E | BJ, AG | 2 | auf Probe 1.38 unten und Mörtel XXV oben | XXXIV | | 3 | | 1 | | | 12 *Soil | | | 1:3 | | Soil gesiebt, Linie bis ca. 6 mm; Auftrag differenziert, links glatt mit Kelle, rechts mit Hand verstrichen | 2h | 3 | 10-40 | 4 | 2 | sandfarben | 01.12. | 4 | 4 | 4 | 3 | sandfarben | Probe Ausblühungsmaterial am 18.01.2012 von Sobott entnommen; keine Risse dazugekommen | | | | durch Salzauswitterungen fleckig heller geworden, verwendbar |
| 1.44 | 12.11. | Pu | QMA2, R101 | Wand G/(F) | N | FR, AG, LO | 3 | auf Probe 1.35 und 1.31 | XXXV | | 3 | | 1 | | 12 | | | ~0,1 masse | 1:3 | | Auftrag differenziert, F/G rechts glatt mit Kelle verstrichen, Kante oben eckig, G links mit Hand verstrichen (F nur halbseitig bearbeitet) | 3h | 4 | 10-40 | 3-4 | 4 | sehr hell | 01.12. | 4 | 4 | 3-4 | 3-4 | hell | keine Risse dazugekommen | | | | Versinterung des Mörtels im geglätteten Bereich, bis ca.20 cm über Boden |
| 1.45 | 12.11. | Pu | QMA2, R101 | Wand B3 unten | E | BJ, AG | 2 | auf Probe 1.32 | XXXIVa | | 3 | | 1 | | | 6 *Soil 6 *Sand | | | 1:3 | | Soil gesiebt, Linie bis ca. 6 mm; rötlicher Wüstensand aus der Umgebung, Auftrag differenziert, links glatt mit Kelle, rechts mit Hand verstrichen | 2h | 3 | 10-40 | 4 | 2 | sandfarben, rötlich | 01.12. | 4 | 4 | 4 | 3-4 | sandfarben, rötlich | keine Risse dazugekommen | | | | durch Salzauswitterungen fleckig heller geworden, verwendbar |
| 1.46 | 12.11. | Mö | | | | | | | XXV | | 2,5 | | 0,5 | | 12 | | | | 1:4 | 0,0833% rot*** | Tests zur Feststellung von Farbgebung im Mörtel durch Pigmente auf der Basis von Mörtel aus Probe 1.31, Probekörper ca. 40x40x4 cm | | | | | | hell rosa rötlich | | | | | | | | | | | |
| 1.47 | 12.11. | Mö | | | | | | | XXV | | 2,5 | | 0,5 | | 12 | | | | 1:4 | 0,1666% ocker**** | Tests zur Feststellung von Farbgebung im Mörtel durch Pigmente auf der Basis von Mörtel aus Probe 1.31, Probekörper ca. 40x40x4 cm | | | | | | sehr hell beige | | | | | | | | | | | |
| 1.48 | 12.11. | Mö | | | | | | | XXV | | 2,5 | | 0,5 | | 12 | | | | 1:4 | 0,1666% rot*** 0,2666% ocker**** | Tests zur Feststellung von Farbgebung im Mörtel durch Pigmente auf der Basis von Mörtel aus Probe 1.31, Probekörper ca. 40x40x4 cm | | | | | | roter Ocker | | | | | | | | | | | |
| 1.49 | 12.11. | Mö | | | | | | | XXV | | 2,5 | | 0,5 | | 12 | | | | 1:4 | 0,1666% rot*** 0,4166% ocker**** | Tests zur Feststellung von Farbgebung im Mörtel durch Pigmente auf der Basis von Mörtel aus Probe 1.31, Probekörper ca. 40x40x4 cm | | | | | | rötlicher Ocker | | | | | | | | | | | |
| 1.50 | 12.11. | Mö | | | | | | | XXV | | 2,5 | | 0,5 | | 12 | | | | 1:4 | 0,250% rot*** 0,050% ocker**** | Tests zur Feststellung von Farbgebung im Mörtel durch Pigmente auf der Basis von Mörtel aus Probe 1.31, Probekörper ca. 40x40x4 cm | | | | | | dunkler rötlicher Ocker | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.51 | 01.12 | Mw, Fu | T9 | | NNE-SSE | FR, LO | 4-5 | Maurermörtel zur statischen und strukturellen Sicherung, Steinaustausch, Vorbereitung OF für Putz | XXVa | | 2,5 | | 1 | | 12 | | | | 1:3,4 | | löste 1.31 ab, Verwendung als Mauer- und Fugenmörtel an T9 und Stadtmauer ca. 10 meter vor T9 von T8 kommend, oberhalb ca. 40 cm über Boden, ab 01.12 | | | | | | | | | | | | | | | | | |
| 1.52 | 01.12. | uPu | QMA2, R103 | Wand B oben | E | FR, LO, AG | 3 | Anwendung Sobott/Ricca bei 19°C/53%rel.F | XXXVI | | 2 | | 1 | | 2 | 10* | | | 1:4 | | Soil aus Umgebung von EP04 (rötlicher als nahe T8) | 1h | 3 | 5-30 | 4 | | | | | | | | | | | | | |
| | | oPu | | | | | | | XXXVII | | 0.75 | | 0,25 | | 1 | 4* | | | 1:5 | | | 3h | 3-4 | 5-10 | 4 | 4 | rötlich erdfarben | | | | | | | | | | | |
| 1.53 | 01.12. | uPu | QMA2, R103 | Wand B oben | E | FR, LO, AG | 3 | Anwendung Sobott/Ricca bei 19°C/53%rel.F | XXXVIII | | 2 | | 1 | | 8 | 4* | | | 1:4 | | Soil aus Umgebung von EP04 (rötlicher als nahe T8) | 1h | 3 | 5-30 | 4 | | | | | | | | | | | | | |
| | | oPu | | | | | | | XXXIX | | 1 | | 0,25 | | 3,5 | 1* | | | 1:3,6 | | | 3h | 3-4 | 5-10 | 4 | 3 | hellgrau erdfarben | | | | | | | | | | | |
| 1.54 | 01.12. | Pu | QMA2, R103 | Wand B oben | E | FR, LO, AG | 3 | Anwendung Sobott/Ricca bei 19°C/53%rel.F | XXXX | | 1 | | | | | 4* | | | 1:4 | | Soil aus Umgebung von EP04 (rötlicher als nahe T8) | 1h | 3 | 5-40 | 3 | 2 | rötlich erdfarben | | | | | | | | | | | |
| 1.55 | 01.12. | Pu | QMA2, R101 | Wand B3 unten | E z.T.F | BJ, AG | 2 | auf Probe 1.28, 1.29 und 1.36, Mörtel basiert auf 1.45 | XXXIVb | | 3,5 | | 1,5 | | 3 | 6 *Soil 6 *Sand | | | 1:3 | | Soil gesiebt, Linie bis ca. 6 mm aus EP04; rötlicher Wüstensand aus der Umgebung; Anwendung siehe gesonderte "manual" | 2h | 4 | 10-60 | 4-5 | 2-4* | sandfarben, leicht rötlich | | | | | | | | | | | |

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|---|---|
| Mw | Mauerwerk |
| VSch | Vorschlemme (unmittelbar vor Auftrag) |
| Sch | Schlemme |
| Fu | Fugen |
| Pu | Putz |
| Mö | reine Mörtelprobe ohne Anwendung on the spot |
| hK | hydraulischer Kalk (Otterbein, Hydradur NHL5) |
| Wkh | Weiskalkhydrat (Bezeichnung!) |
| sPz | sulfatbeständiger Portlandzement (Bezeichnung!) |
| An | Anhydrit (Herstellung über QMA) |
| Wzm | Weißzement (Bezeichnung!) |
| Qs | Quarzsand (0,0-02, vereinzelt bis 0,6) |
| Mks | Muschelkalksand (0,75-2 und 2,5-6, gewaschen, Eigenherstellung) |
| Ty | Thylose MH 30.000 (Deffner & Johann) |
| Pig | Pigmente (Deffner & Johann) |
| * | Soil= Abraum aus Ausgrabung Zubarah |
| ** | Sand= rötlicher Wüstensand |
| *** | lichtechtes Pigment "Italienische Erde rot Veneto" |
| **** | lichtechtes Pigment "lichter Ocker" |

Der bis 02.12. verwendete Wüstensand wird an Strasse nach Shamal, ca. 1000 meter nach Höhe Freya an den beiden freistehenden Felsformationen gewonnen.

Angelegte Probeflächen ab Juni 2010

**2. Festigung historischer Putze**

| Identifikation | | | | | | | Untergrund | | | | Materialien | | | | | | | | | | | Verarbeitung | | | | | Begutachtung -visuell | | | | Begutachtung Labor | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Festigungsmittel | | | | | Zuschlag | | | | | | | | | | | | | | | | | | |
| Probe-Nr. | Monat/Jahr Probe | Anwendungsort | Raum/Lokus | Wand | Position auf Wand | Ausrichtung | Risse 1=viel - 5= keine | Absanden 1=viel - 5= kein | Bröckelzerfall 1=viel - 5= kein | Bemerkung | Khy E10 | Khy E25 | H2O in ml | Tyl in g | Acr in % | | | | | Pig (%) | Bemerkung | Grösse der Fläche in cm | Applikation ein/mehrfach | Auftrag | Farbveränderung naß 1=stark verdunkelnd - 5=keine Veränderung | Farbveränderung trocken 1=stark verdunkelnd - 5=keine Veränderung | Monat/Jahr | festigende Wirkung 1=schlecht - 5=sehr gut | Farbveränderung 1=stark verdunkelnd - 5=keine Veränderung | Bemerkung | Datum Analyse | | | Bewertung |
| | 2010 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.1 | 06.10 | QMA2 | R103 | B | mi. un. | E | 3 | 3-4 | 5 | | X | | | | | | | | | | sehr schnelle Trocknung | 30x20 | 2 | Pin. | 1-2 | 4-5 | 12.10 | 1-2 | 4 | kaum Wirkung feststellbar, weißer Schleier | | | | nicht verwendbar |
| 2.2 | 06.10 | QMA2 | R103 | B | mi. un. | E | 3 | 3-4 | 5 | | | X | | | | | | | | | sehr schnelle Trocknung | 35x20 | 2 | Pin. | 1-2 | 4-5 | 12.10 | 1-2 | 4 | kaum Wirkung feststellbar, weißer Schleier | | | | nicht verwendbar |
| | 2012 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.3 | 01.12. | QMA2 | R144 | B | mi. li. un. | E | 4-5 | 1 | 2 | Reste ehemaliges Gewände (?), sehr stark verwittert, aktiv | | | 400 | 2 | 5 | | | | | | linkes Gewände mitte | 20x20 | 1 | Pin. | 3 | 3 z.T. milchig blass | | | | geringe Aufnahme des Untergundes | | | | |
| 2.4 | 01.12. | QMA2 | R144 | B | mi. li. un. | E | 4-5 | 1 | 2 | Reste ehemaliges Gewände (?), sehr stark verwittert, aktiv | | | 400 | 4 | 5 | | | | | | rechtes Gewände mitte | 20x20 | 1 | Pin. | 3 | 4 | | | | geringe Aufnahme des Untergundes | | | | |
| 2.5 | 01.12. | QMA2 | R144 | B | mi. li. un. | E | 4-5 | 1 | 2 | Reste ehemaliges Gewände (?), sehr stark verwittert, aktiv | | | | | 7 | | | | | | linkes Gewände oben | 20x15 | 2 | Pin. | 1-2 | 4 | | | | geringe Aufnahme des Untergundes | | | | |

| | |
|---|---|
| mi. | mitte |
| un. | unten |
| re. | rechts |
| li. | links |
| Pu | Putz |
| Pin. | Pinsel |
| Spr. | Spritze |
| Khy E10 | Kalziumhydroxid auf Nanobasis (kolloidales Kalziumhydroxid), Nanokalk in Ethanol, 10% |
| Khy E25 | Kalziumhydroxid auf Nanobasis (kolloidales Kalziumhydroxid), Nanokalk in Ethanol, 25% |
| Tyl | Thylose MH 30.000 (Deffner & Johann) |
| Wzm | Weißzement (Bezeichnung!) |
| Qs | Quarzsand (0,0-02, vereinzelt bis 0,6) |
| Mks | Muschelkalksand (0,75-2 und 2,5-6, gewaschen, Eigenherstellung) |
| Pig | Pigmente (Deffner & Johann) |
| Soil | Soil anstehend gesiebt auf ca. 0-5 mm oder soil dessert= roter Wüstensand ungesiebt |

# APPENDIX 3

# ANALYSES OF BUILDING MATERIALS

## AT AL ZUBARAH / QATAR

Report by Robert Sobott

June 2011

*Dhow etching, Az Zubarah, 2009*

**QATAR ISLAMIC ARCHAEOLOGY AND HERITAGE PROJECT**

**مشروع قطر لعلم الآثار و التراث الإسلامي**

**The Qatar Museums Authority**
***in partnership with***
**The University of Copenhagen**

# REPORT ON THE BUILDING MATERIALS OF AL ZUBARAH CITY


ROBERT J. SOBOTT

DR. RER. NAT.


JUNE 2011

**Summary:** An appraisal of the historic building materials of Al Zubarah city was made. All building stones encountered in the walls are available in the immediate vicinity of the city. Four main groups of building stones were found: beachrock, aeolianite, dolomitic limestone, and gypsum. The beachrock can be further differentiated into at least two or three subgroups one of which is a conglomerate made up of beachrock and dolomite fragments. The quality of the building stones with respect to strength and weathering resistance varies greatly. The beachrock varieties are generally of poor quality and should not be considered for repair work. Although endowed with totally adverse properties, the aeolianite and the dolomitic limestone are very good building stones. The first is light and porous, the latter heavy and dense. They complemented one another ideally if the dense dolomitic limestone was used for the basement and the porous aeolianite for the following stonework. The dense dolomitic limestone would act as a barrier against the capillary rise of water while the porous aeolianite with a low heat conductivity would keep the heat out of the inner parts of the building. As the aeolianite is outcropping some 15 km NE of Al Zubarah it would be possible to quarry fresh material. Also the dolomitic limestone can easily be collected from the surface.

The mortar used at the time of the building of Al Zubarah city was most probably an anhydrite mortar. While the plaster is well preserved, the wall mortar - if still present – is in a bad condition. This means that the consolidation of walls requires a lot of repointing. In many cases even this will not suffice to regain stability and a complete reconstruction of wall parts will be necessary.

For this repair and reconstruction work suitable mortars will be needed. Tests have been made with natural hydraulic lime mortar and different mixtures of anhydrite mortar. The tests with natural hydraulic lime mortar were successful and this mortar type can be used for the reconstruction of the walls and the repointing of joints. Much attention has to be paid to the selection of the aggregate so that the colour of the joints harmonizes with the colour of the stones. The longevity of the mortars will be increased if salt-free aggregate is used.

The results with anhydrite mortars are not conclusive yet. However, mixtures of anhydrite with natural hydraulic lime seem to very promising. As in the past, anhydrite mortar will preferably be used for plastering the walls. The plaster acts as a protective coating for the wall and prevents the fast erosion of joints by the ever-blowing wind. Depending on the outcome of ongoing tests, it is conceivable to use anhydrite mortar also for reconstruction work and repointing.

## Part 1 : The building stones

## 1 Introduction

In December 2010 and March 2011 the walls of the ruined city of Al Zubarah were surveyed with respect to the building materials, i. e. the building stones, the mortars, and wall plasters. The inspection revealed that a number of different sedimentary rocks was used which differ widely in the constituent components, mineralogical composition, and fabric. Consequently, also the petrophysical parameters and the weathering stability are quite different what is reflected by the variable state of preservation of the walls. Figure 1 gives an example on how the rock properties contribute to the stability of the wall structure. The gradual and specific decay of the different building stones contributes also to the decay of the mortar in the joints and both processes will eventually lead to a collapse of wall structures.

**Figure 1: Preservation state of wall structures as a function of mortar and rock stability.**
Left side: Homogeneous aeolianite building stones with good weathering stability and moderate mechanical strength. Right side: Beachrock type with poor weathering stability and mechanical strength.

All the building materials come from the surroundings and are linked to the regional geology of the Al Zubarah region. The rock material is derived from the Eocene Dammam dolomitic limestone and the sediments deposited on it, namely the Pleistocene aeolianites (fossil sand dunes), the mid-Holocene beachrocks, and gypsum concretions of the sabkhat (Macumber, 2009). Figure 2 presents a simplified geological profile of the Al Zubarah region in which potential areas for quarrying the building stones are marked. Figure 3 shows the sand-covered relics of a former quarry of aeolianite at Gabal Freha, an outcrop of the Dammam dolomite in surrounding beachrock, and gypsum concretions on the sabkha surface.

From the city wall, a tower construction, and a housing complex of the Zubarah archaeological excavation site as well as as from rock outcrops in the vicinity of Al Zubarah several specimen were samples and subjected to a mineralogical and petrographical study. The qualitative mineralogical composition was determined by X-ray diffractometry, the rock components and fabrics were investigated by optical microscopy of thin sections.

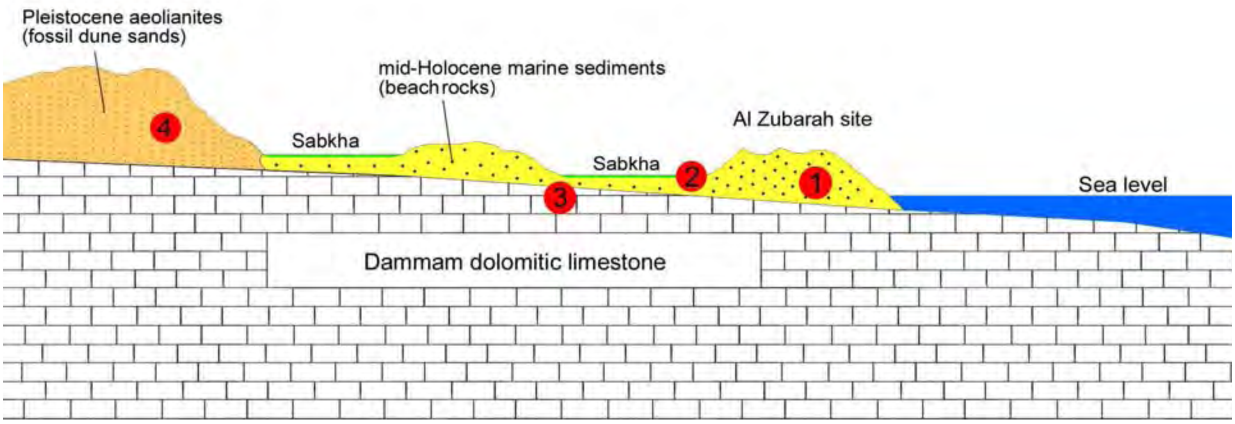


**Figure 2: Geological profile of the Al Zubarah region (modified after Macumber, 2009).**
Red dots mark potential sources of the building stones. 1 Different types of beachrock, 2 Gypsum concretions, 3 Dammam dolomitic limestone, 4 Aeolianites

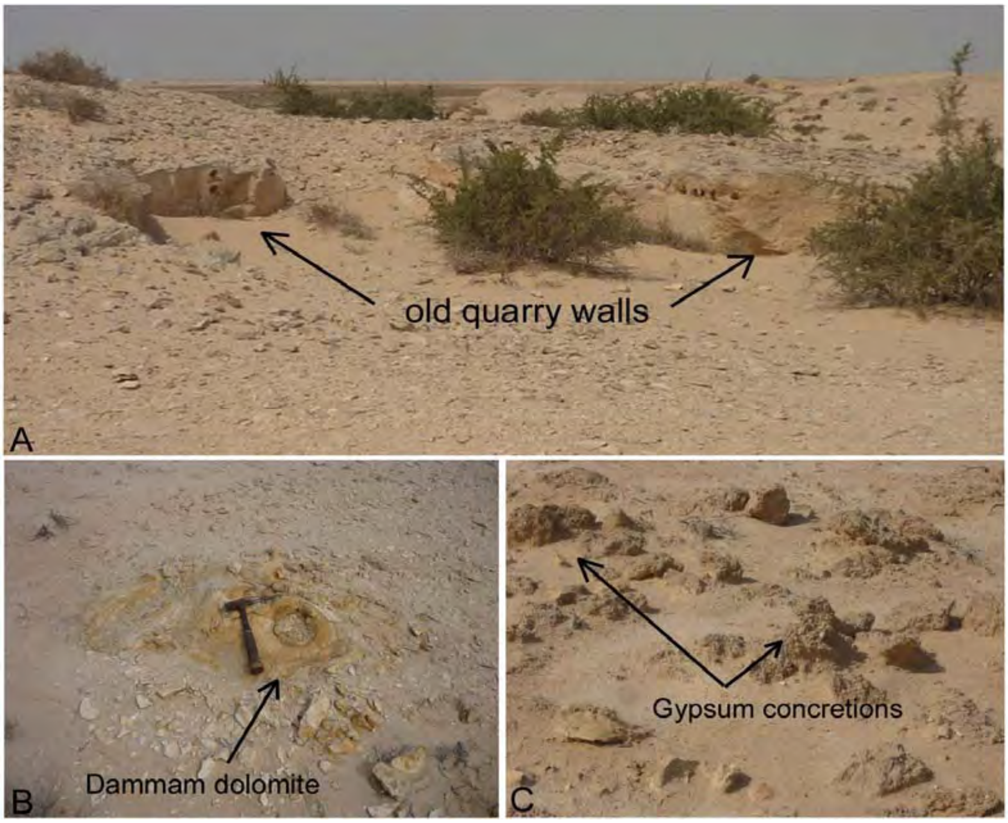


**Figure 3: Outcrops of building stones present in the walls of Al Zubarah.**
A. Old, sand-covered quarry at Gabal Freha, B. Outcrop of Dammam dolomite in beachrock, C. Gypsum concretions (gypcrete)on sabkha surface

## 2 The different rock types

The principal rock types present in the city walls of Al Zubarah are beachrock, aeolianite, dolomitic lime stone and gypsum concretions (gypcrete). Depending on the prevalent fossil type and particle size, the beachrock can be differentiated in mollusc and gastropod grain and/or rudstones. Figure 4 shows representative samples of each type. While the beachrock is variable with regard to the fossils, the particle size, and the component/matrix ratio, the aeolianite, dolomitic lime stone, and gypcrete are structurally and mineralogically rather homogeneous. Table 1 summarizes macroscopic features by which the rocks can be determined in the field.

**Table 1: Characteristic macroscopic features of the building stones**

| Rock type | Colour | Macroscopically visible components | Hardness | Diagnostic features |
|---|---|---|---|---|
| **Beachrock** | light yellow grey to whitish | bivalves, gastropods | friable | components |
| **Conglomerate** | mixed colours of rock constituents | bivalves, gastropods, dolomite fragments | - | components |
| **Aeolianite** | light yellow | - | medium | medium grain size, bedding |
| **Dolomitic limestone** | fresh surface grey | - | very hard | density, fine grain size |
| **Gypsum** | yellow grey to whitish | - | soft | scratchable with finger nail |

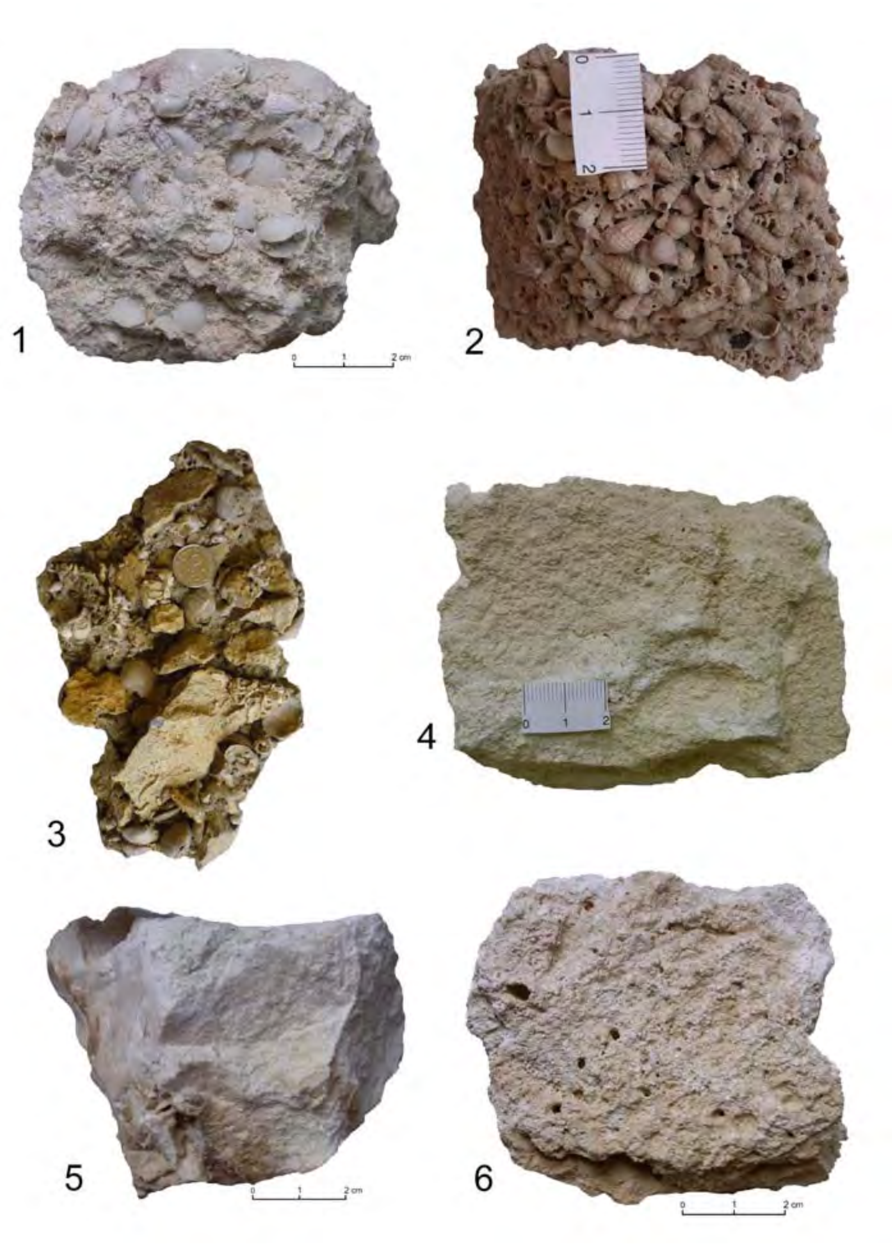


**Figure 4: The principal rock types in the walls of Al Zubarah.**
1: Beachrock AG (mollusc rudstone), 2: Beachrock BJ (gastropod rudstone),
3: Conglomerate, 4. Aeolianite FR, 5: Dolomitic limestone BL, 6: Gypsum rock BE

## 2.1 Mineralogical composition of the building stones

The samples for the determination of the mineralogical composition by X-ray diffraction with CuK$\alpha$-radiation were prepared by grinding rock fragments in a tungsten carbide mortar and separation of the grain size fraction 0,063 – 0,1 mm by sieving. If diffraction peaks of halite and/or quartz were present in the rock (or mortar) samples, they were used for the 2$\theta$-calibration of the corresponding X-ray diffractogram. The phase detection limit was in the range of 1 - 2 mass%.

The results of the X-ray diffractometry are summarized in table 2. The phases are listed from left to right in the order of decreasing quantity. Phases put in brackets are not constituents of the rocks (or mortars) but of secondary origin such as halite which crystallizes from saline groundwater or seawater spray. All X-ray diffractograms are displayed in the appendix.

**Table 2: Mineralogical composition of the building stones**

| Rock type | Code | Mineral phases |
|---|---|---|
| **Beachrock type I (silty carbonate sand with abundant bivalves)** | **AG** | Mg calcite II, Mg calcite I, aragonite, dolomite, (halite), clay mineral ? |
| **Beachrock type II (silty carbonate sand with abundant gastropods)** | **BJ** | Mg calcite II, Mg calcite I, aragonite, dolomite, (halite) |
| **Aeolianite** | **FR** | calcite, dolomite, plagioclase, quartz, Mg calcite II |
| **Dolomitic limestone** | **BL** | dolomite, (halite) |
| **Gypsum rock (gypcrete)** | **BE** | gypsum, Mg calcite II, aragonite, dolomite |

The carbonate mineralogy of the beachrocks is determined by the presence of two Mg calcites with different amounts of $MgCO_3$ and aragonite. Mg calcite and aragonite are two $CaCO_3$ species which are precipitated from sea water with a molar Mg/Ca ratio > 2 (Ries, J. B., 2005). According to Goldsmith, Graf and Joensuu (1955) the $MgCO_3$ content of Mg calcite can be derived from the position of the (104) reflection of calcite by using the relationship Mol % $MgCO_3$ = 791,4 – 260 x $d_{(104)}$ [Å]. Mg calcite I contains less than 7 Mol% $MgCO_3$, Mg calcite II more than 13 mol % $MgCO_3$. Mg calcite and aragonite are metastable phases at ambient temperature and pressure conditions and transformed to stable calcite by a dissolution/precipitation process within a comparatively short time span. Koch and Rothe (1985) described the transformation of Miocene Mg calcite grains of 4 – 10 µm length and 1 – 3 µm diametre to stable calcite by the reaction with meteoric water within 10 – 20 years. Beachrock samples with different Mg calcite II/Mg calcite ratios indicate that the transformation process is controlled by the exposure to rainfall. Better protected stones inside a wall retain a Mg calcite II/Mg Calcite I ratio > 1 while exposed rocks exhibit a Mg calcite II/Mg Calcite I ratio < 1. A good example for an exposed beachrock is the “table stone” shown in figure 5 which has retained only little Mg calcite II. The transformation of Mg calcite to calcite is combined with a release of $Mg^{2+}$ ions and a potential source for the formation of harmful magnesium salts.

Also the dolomite of the beachrock is non-stoichiometric and shows an excess of calcium (Ca dolomite). The dolomite composition was determined by evaluating the position of the (104) diffraction peak and the relationship $d_{(104)}$ = 1,8786*$10^{-5}$ x (mol% $CaCO_3$)² + 5,022*$10^{-3}$ x mol% $CaCO_3$ + 2,681 was used to calculate the mol percentage of $CaCO_3$ (Goldsmith, Graf and Joensuu, 1955).

**Figure 5: “Table stone” (beachrock) within the walls of a building, Al Zubarah**

While quartz can also be identified in the X-ray diffracrograms of the beachrocks the diagnostic potassium feldspar diffraction peak is masked by the (021) peak of aragonite. However, optical microscopy reveals that potassium feldspar and plagioclase are present in the beachrocks as detrital grains (see figures 6 and 7).

In the older Pleistocene aeolianites Mg calcite has almost been completely transformed to stable calcite by meteoric water percolating through the pores. Therefore, calcite is the dominating phase in the X-ray diffractogram of sample FR. Further low intensive diffraction peaks can be attributed to dolomite, plagioclase, quartz, and Mg calcite II.

The Damman dolomitic limestone consists almost completely of stoichiometric dolomite. The small diffraction peak at 2Θ (CuKa) = 31.69° is due to halite which adhered to the sample surface.

Logically, gypsum is the dominating phase in the X-ray diffractogram of the gypsum rock which also shows diffraction peaks for Mg calcite II, aragonite, and dolomite which are less soluble in sea water than gypsum and formed as first precipitates. Interestingly enough there is no indication of the occurrence of anhydrite in the gypsum rocks. The formation of anhydrite by dehydration of gypsum might be expected since the reaction takes place at temperatures around 50 °C and this temperature will be reached on the surface of gypsum rocks during the summer period.

## 2.2 Petrography of the building stones

### 2.2.1 Beachrock type I (silty carbonate sand with abundant bivalves)

This beachrock type is characterized by the abundance of bivalves (peleycpods Chione) embedded in a silty carbonate sand matrix. Apart from the bivalves other fossils observed in the thin section are gastropods, forams, and peloids (figure 6). The latter are sometimes filled with chalcedony.

Non-carbonate particles include quartz and feldspar grains (K feldspar and plagioclase). The transformation of Mg calcite and aragonite to the stable modification calcite has not set in yet and the particles are just weakly cemented. Hence the compressive strength of this rock is very low.

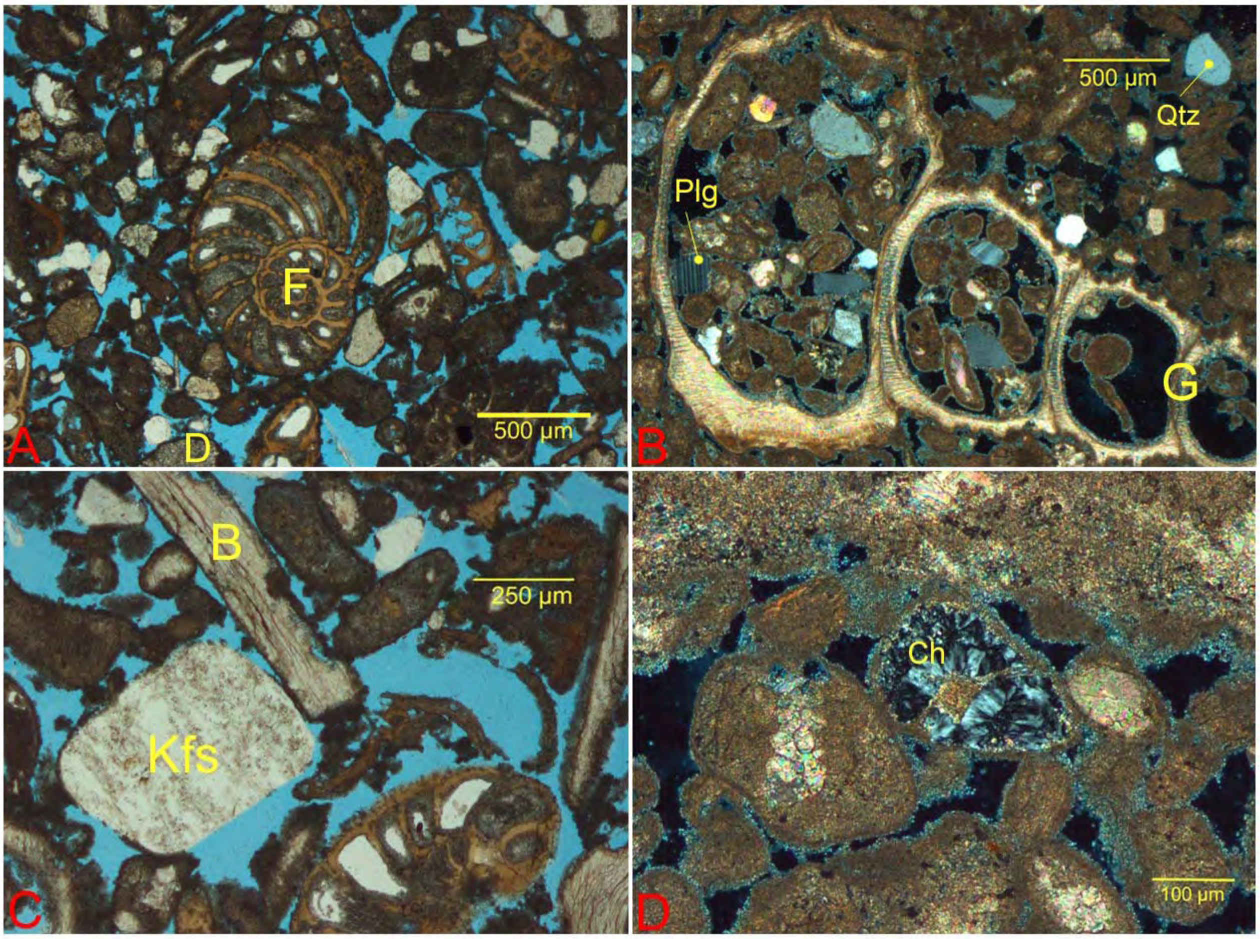


**Figure 6: Thin section photographs of beachrock 1 (silty carbonate sand with mollusc debris)**

A. Plane-polarized light. Grain-supported fabric. Foraminifera (F) in the centre, small dolomitic rock fragment (D) at the bottom.
B. Crossed polars. Gastropod cross section (G). Chambers are filled with internal sediment (quartz (Q), plagioclase (Plg).
C. Plane-polarized light. Grain-supported fabric with large K feldspar grain (Kfs) and bivalve fragment (B).
D. Crossed polars. Peloids, one with chalcedony (Ch) filling

### 2.2.2 Beachrock type II (silty carbonate sand with abundant gastropods)

The biogenic detritus of this beachrock type consists mainly of gastropods embedded in a silty carbonate matrix (figure 7). Non-carbonate particles include quartz and feldspar grains and dolomite rock fragments (extraclasts). As in beachrock type I Mg calcite and aragonite are not transformed to stable calcite and no calcitic cements occurs. Therefore this rock has also a low compressive strength.

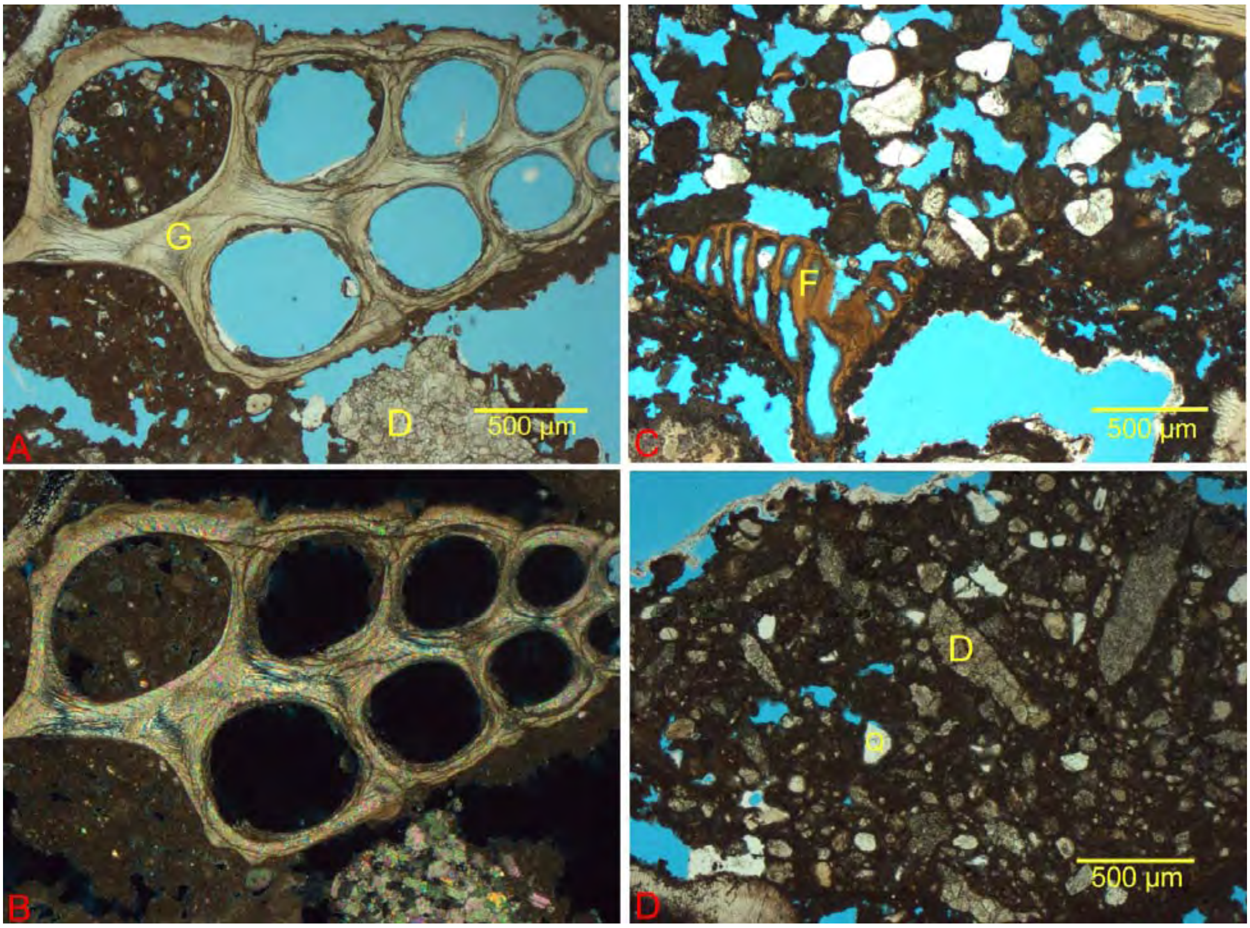


**Figure 7: Thin section photographs of beachrock 2 (silty carbonate sand with gastropods)**

A. Plane-polarized light. Gastropod cross section (G) with one chamber filled with internal sediment, dolomite fragment (D)
B. same frame as A, however between crossed polars
C. Plane-polarized light. Grain-supported fabric, foraminifera (F)
D. Plane-polarized light. Silty carbonate sand with dolomite fragments (D) and quartz grains (Q)

### 2.2.3 Aeolianite (Peloidal grainstone)

The aeolianite has a grain-supported fabric of biogenic detritus (forams, bryozoa, peloids). Contrary to the beachrocks the particle size distribution is very homogeneous with a pronounced maximum centred around 200 µm. The observation of granular calcite cement around biogenic particles in the thin section (figure 8) is corroborated by the result of X-ray diffractometry. This rock contains no more aragonite and only very little Mg calcite which have been transformed to stable calcite under the influence of meteoric water percolating through the pores. The less soluble stoichiometric calcite was precipitated from the pore water and formed the granular cement. Apart from the biogenic components the aeolianite contains dolomite fragments and quartz and feldspar grains. The markedly higher compressive strength is due to the calcitic cementation of the particles.

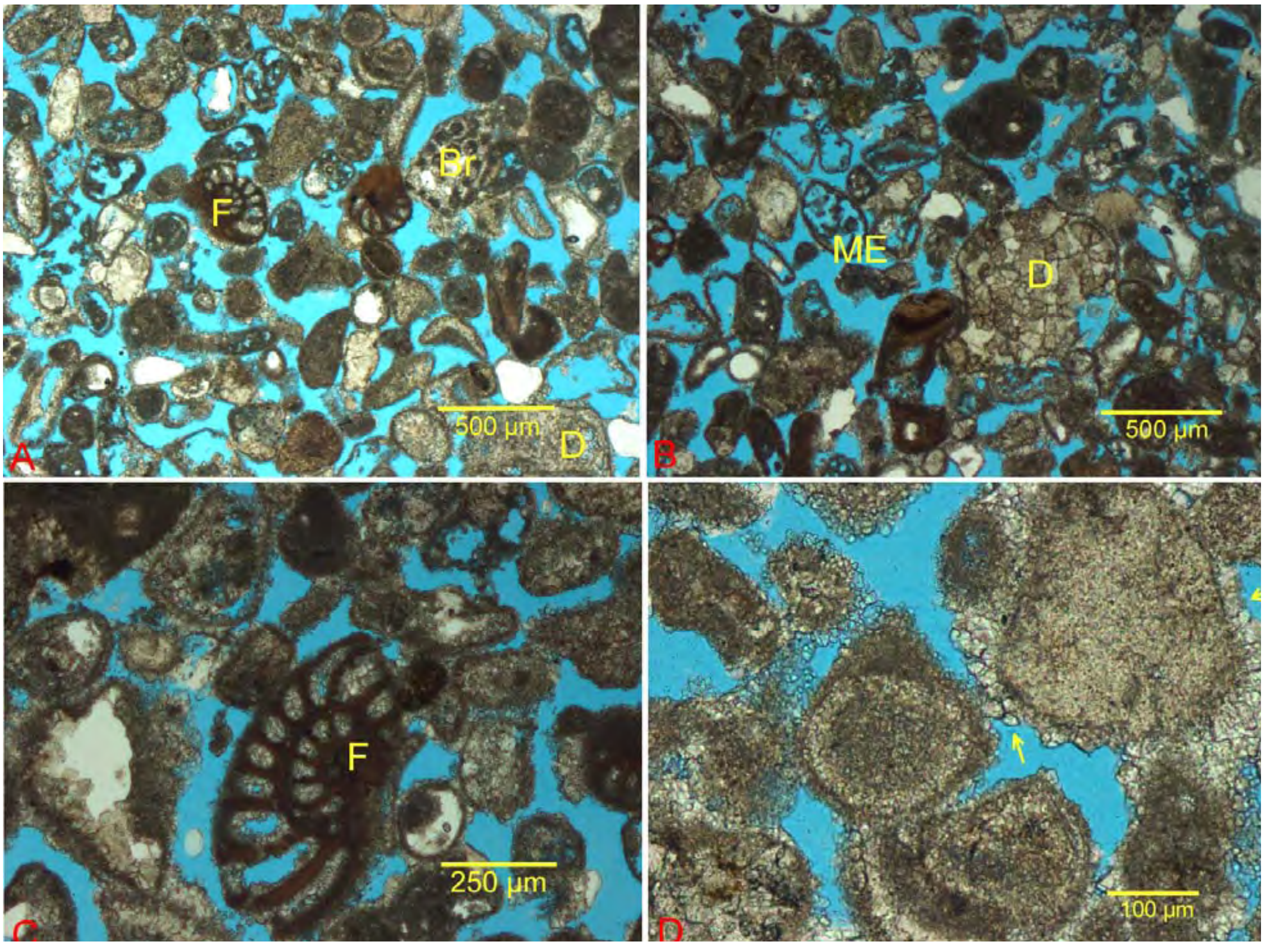


**Figure 8: Thin section photographs of aeolianite (peloid grainstone)**

A. Plane-polarized light. Grain-supported fabric with foraminifera (F) and bryozoa (Br)
B. Plane-polarized light. Peloids with micritic envelopes, dolomite fragment (D).
C. Plane-polarized light. Foraminifera (F) with calcite filling in chambers, granular calcite around biogenic particles
D. Plane-polarized light. Granular calcite cement (yellow arrows) around biogenic particles

### 2.2.4 Dolomitic limestone

Optical microscopy of the thin section of the Dammam dolomitic limestone reveals a typical succrosic dolomite fabric with practically no intercrystalline porosity. With few exceptions the dolomite crystals are fine-grained (< 100 µm) and exhibit a distinct zoning (lower left photograph in figure 9). This zoning is due to different chemical composition of the core and rim. This finding, however, is surprising as the X-ray diffractogram of this rock (see appendix) shows only diffraction peaks for stoichiometric or near stoichiometric dolomite ($Ca_{50}Mg_{50}$). A characteristic feature of the dolomitic limestone is the occurrence of vugs which range in size from less than a millimetre to several centimetres. Also the $SiO_2$ content in the form of fibrous chalcedony is only detectable in the thin section and not in the X-ray diffractogram which means that it is below the detection limit of 1 – 2 mass%. The dense fabric of interlocked dolomite crystals gives the rock a high compressive strength.

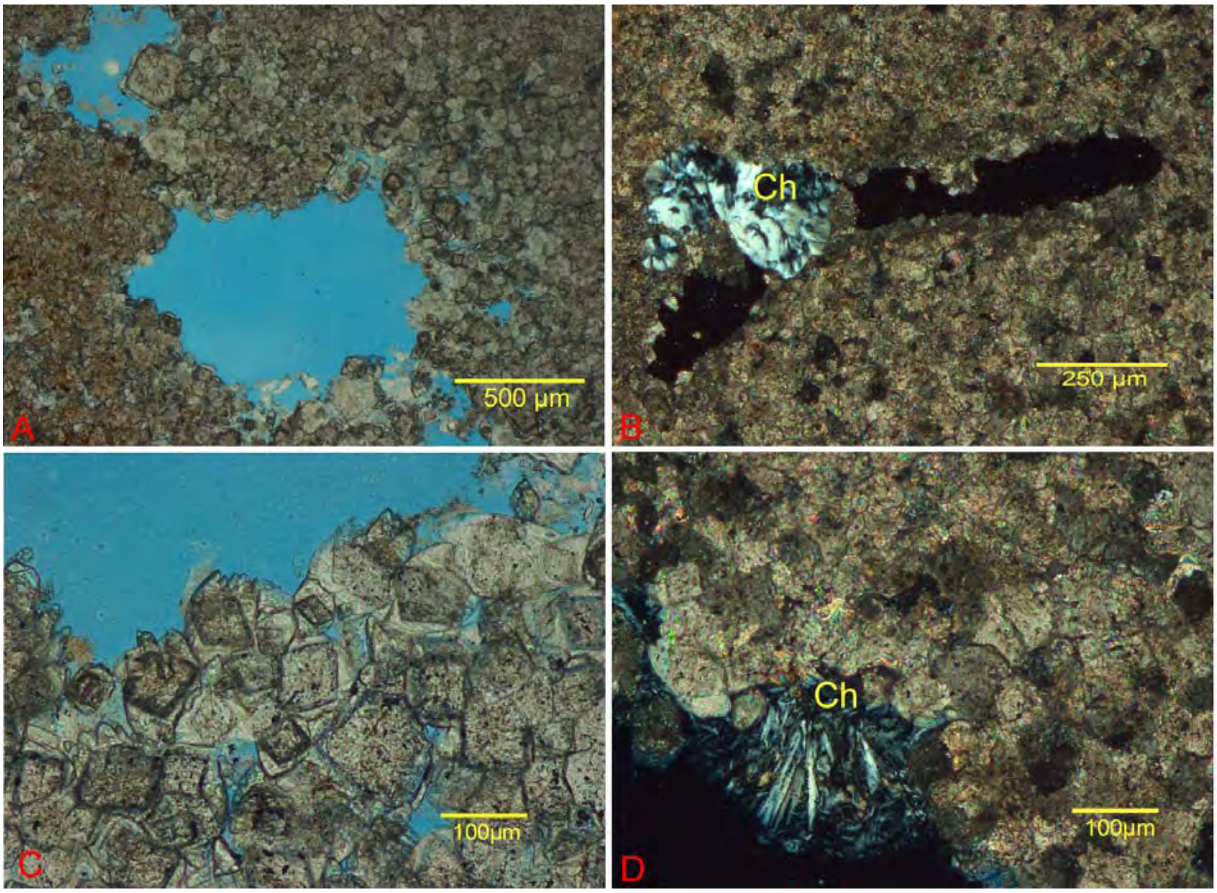


**Figure 9: Thin section photographs of dolomitic limestone**

A. Plane-polarized light. Fine-grained succrosic dolomite with vug (blue).
B. Crossed polars. Chalcedony (Ch) aggregate in succrosic dolomite with elongated vug.
C. Plane-polarized light. Zoned rhombohedral dolomite crystals.
D. Crossed polars. Chalcedony (Ch) fibres pointing to vug in succrosic dolomite.

### 2.2.5 Evaporitic mudstone (gypsum)

The evaporitic mudstone is a sediment of the sabkha facies. The dominant evaporitic minerals of the sabkha are gypsum, halite, and anhydrite. Therefore it is surprising that according to X-ray diffractometry the sample consists almost exclusively of gypsum and contains no anhydrite or halite. Also the optical microscopy of a thin section of this sample revealed no anhydrite which can easily be recognized by its bright second order green and yellow birefringence colours. Between crossed polars the cryptocrystalline gypsum appears as a dull dark brown mass and only where it recrystallized to greater crystals the grey and white birefringence colours are clearly visible (lower right photograph in figure 10). The mud matrix also contains dolomite fragments, feldspar grains, and shell debris.

## 2.3 Basic petrophysical parameters of the building stones

Prisms cut from handspecimens with a diamond saw blade and measuring 2 x 4 x 5 cm³ were used for the determination of some basic petrophysical parameters. Bulk density was determined as the quotient of the mass and calculated volume of a prism, porosity as the quotient of pore volume, measured by the imbibition method, and calculated volume of a prism. The ultrasonic velocity was measured in the transmission mode and is directly related to the density and elastic modulus.

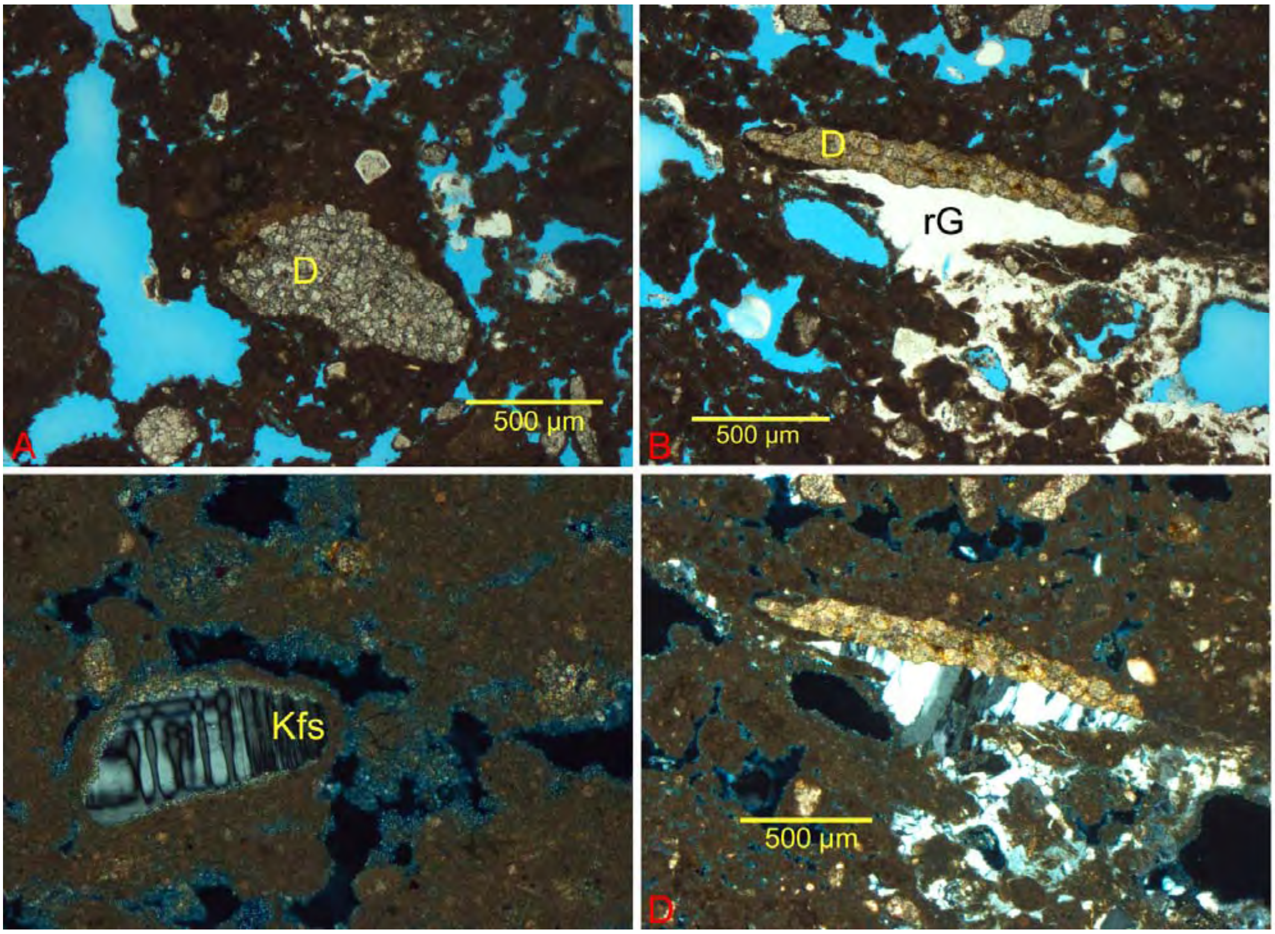


**Figure 10: Thin section photographs of evaporitic mudstone (gypsum)**

A. Plane-polarized light. Evaporitic mud (gypsum) with dolomite (D) fragments and large pores (blue).
B. Plane-polarized light. Evaporitic mud with dolomite fragments, recrystallized gypsum (rG) and large pores (blue).
C. Crossed polars. K feldspar (microcline) (Kfs) grain in gypsum matrix
D. Crossed polars. Same frame as B

Abdullatif (2009) investigated the geomechanical properties of carbonate rocks from the Rus formation and Dammam dome in Saudi Arabia and established a number of linear and non-linear correlations between individual parameters such as point load strength vs. unconfined compressive strength, density vs. porosity, and point load strength vs. Schmidt hammer rebound number. The data can be used to evaluate in situ measurements on building stones at Al Zubarah city with the Schmidt rebound hammer with respect to point load strength and unconfined compressive strength.

**Table 3: Basic petrophysical parameters of the building stones**

| Sample | Rock type | Bulk density [g/cm³] | Porosity [ % ] | Ultrasonic velocity [km/s] |
|---|---|---|---|---|
| **AG** | beachrock I | 1,54 | ~ 40 | 2,6 |
| **BJ** | beachrock II | 1,56 | ~ 30 | 3,8 |
| **FR** | aeolianite | 1,63 | ~ 40 | 3,1 |
| **BI** | microcrystalline dolomite | 2,55 | < 10 | 4,9 |
| **BE** | evaporitic mudstone (gypsum) | 1,50 | ~ 39 | 2,5 |

## Part 2: Historic mortars

## 3 Introduction

The term “historic mortar” implies that it dates back to the time of construction of a building or its restoration before the beginning of the Qatar Islamic Archaeology and Heritage Project (QIAH). A number of samples were taken from the mosque at Freha, the excavation site South field (room 005, wall C) and the area of consolidation at Al Zubarah city (figure 11), Al Zubarah fort, and the Al Rikiyat fort (figure 13). X-ray diffraction analysis was used to identify the qualitative composition of samples from which conclusions can be drawn with respect to the nature of a mortar ( anhydrite/gypsum or lime/hydraulic lime mortar). Three different kind of reactions can be differentiated (compounds printed in bold characters are detetctable by X-ray diffraction, mineral names given in brackets):

**Anhydrite mortar** $\mathbf{CaSO_4} + 2H_2O \rightarrow \mathbf{CaSO_4{*}2H_2O}$
(anhydrite) (gypsum)

**Pure lime mortar:** $\mathbf{Ca(OH)_2} + CO_2 \rightarrow \mathbf{CaCO_3} + H_2O$
(portlandite) (calcite)

**Hydraulic lime mortar:** $2\mathbf{Ca_2SiO_4} + 4H_2O \rightarrow \mathbf{Ca(OH)_2} + Ca_3(SiO_3OH)_2{*}2H_2O$
(dicalciumsilicate) $\mathbf{Ca(OH)_2} + CO_2 \rightarrow \mathbf{CaCO_3} + H_2O$

The purpose of this investigation was to get an idea what kind of mortars were used for the building and plastering of the walls. The results were also used for the development of repair mortars which are compatible with the mortar inventory of the historic buildings. Table 4 lists the investigated historic mortars with their phase composition.

**Table 4: Historic anhydrite and (hydraulic) lime mortars and their phase composition**

| No. | Sampling locality | Mortar type | Phase composition |
|---|---|---|---|
| 1 | Freha, mosque | anhydrite wall mortar | dolomite, gypsum, Mg calcite I, quartz, (halite), plagioclasi, K feldspar, aragonite |
| 2 | Freha, mosque | anhydrite plaster, lower layer | gypsum, (halite) |
| 3 | Freha, mosque | anhydrite plaster, upper layer | gypsum, (halite), quartz |
| 4 | Al Zubarah, area of consolidation | anhydrite plaster | gypsum, anhydrite |
| 5 | Al Zubarah, South field, | anhydrite plaster | gypsum, calcite, quartz, (halite), anhydrite |
| 6 | Al Zubarah fort | hydraulic lime mortar | quartz, calcite, gypsum |
| 7 | Al Rikiyat fort | hydraulic lime mortar | quartz, calcite, |

## 4 Anhydrite-based mortars

Mortars dating back to the construction of the buildings are generally anhydrite based mortars. They were produced by burning gypsum at temperatures between 400 – 1000 °C. The complete dehydration of gypsum results in the formation of anhydrite II, a complex mixture of anhydrite modifications with different water solubility. The reaction of anhydrite with water to form gypsum is very sluggish and requires an activator in order to have reasonable setting times in the range of a few days. Possible activators are sodium sulphate or calcium oxide (burnt lime).

The formation of gypsum from anhydrite is connected with an increase in volume by 60.8%, the dehydration of gypsum to anhydrite by a loss of volume of 37.8%. Since the dehydration of gypsum starts at temperatures around 50 °C this reaction could happen in gypsum wall plasters exposed to the sun. The repeated shrinkage and swelling of a surface layer of the plaster may eventually lead to its deacay. The presence of anhydrite in plaster samples in the range of about 2 mass% was observed by X-ray diffractometry in two plaster samples .


**Figure 11: Sampling localities at Freha and at Al Zubarah. A. Double-layered wall plaster at Freha mosque, B. wall mortar at Freha mosque, wall plaster at Al Zubarah city, South field R.005, wall C (C) and Al Zubarah city area of consolidation (D)**

The phase composition of the anhydrite mortar reflects the type of production. If pure anhydrite was used as binder and small fragments of anhydrite as aggregate then the corresponding X-ray diffractogram predominantly exhibits the diffraction peaks of gypsum. Other phases present may be quartz, calcite, anhydrite, and the ubiquitious halite. If the anhydrite binder was mixed with shell sand as aggregate then the corresponding X-ray diffractogram contains X-ray diffraction peaks of aragonite and Mg calcite as additional phases (table 4). The investigated historic anhydrite mortars and plasters contain practically no or only very little anhydrite which means that the anhydrite was more or less completely transformed to gypsum and that the reverse reaction of dehydration of gypsum due to insolation is not so common as would be expected on the basis of theoretical considerations.

The optical microscopy of thin sections reveals that the anhydrite mortars are characterised by a porous matrix which contains only little aggregate particles. These may be quartz grains or sedimentary rock fragments. Usually the gypsum is cryptocrystalline but sometimes larger, recrystallized aggregates are encountered (figure 12).

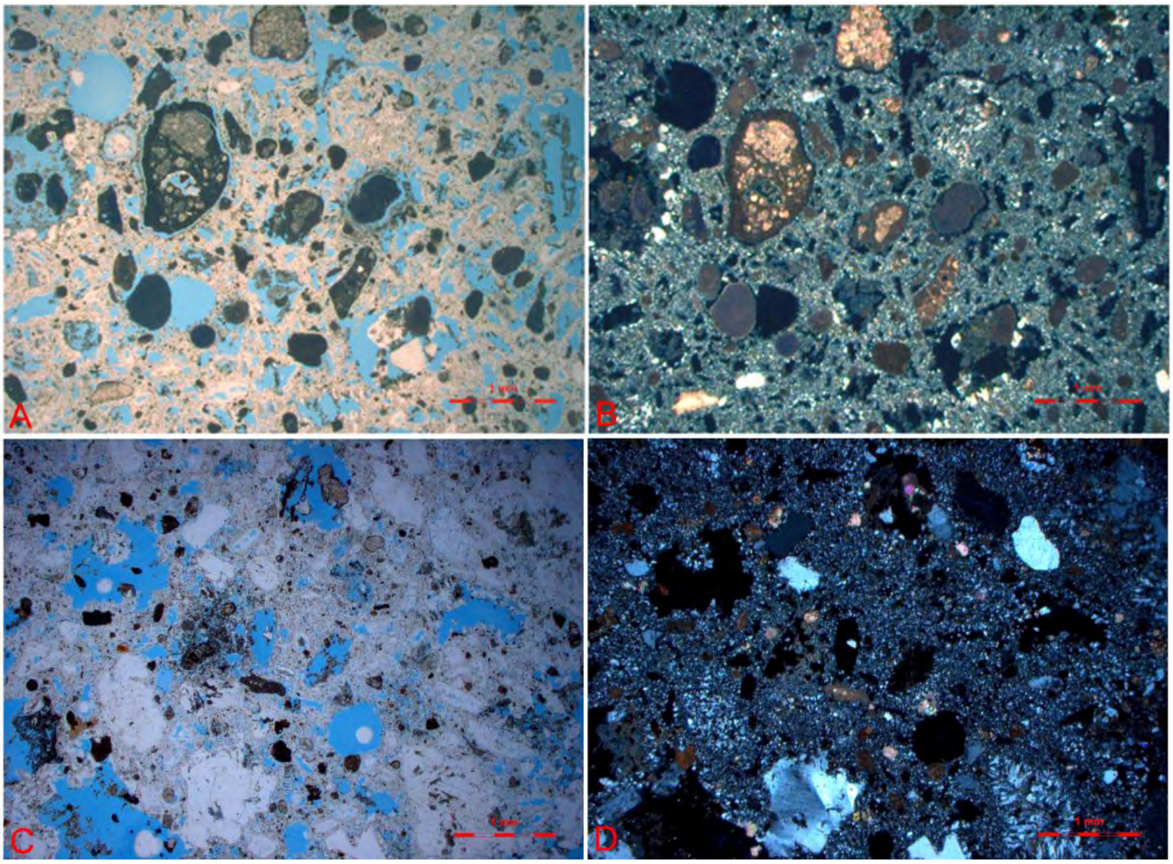


**Figure 12: Thin section photographs of historic anhydrite plaster from a wall in South field, Al Zubarah city (A, B) and the the mosque at Freiha (C,D)**

A: Plane-polarized light. Rock fragments and quartz grains embedded in porous gypsum matrix. B: same frame as A but between crossed polars.

C: Plane-polarized light. Gypsum and quartz grains embedded in porous gypsum matrix. B: same frame as C but between crossed polars.

## 5 (Hydraulic) lime-based mortars

(Hydraulic) lime-based mortars were obviously used for earlier repair work at the forts of Al Zubarah and Al Rakayat. The corresponding X-ray diffractograms are marked by strong diffraction peaks for quartz (aggregate) and calcite (binder). Usually the aggregate contains not only quartz but also feldspar (K feldspar and/or plagioclase). Additional diffraction peaks attributed to gypsum or dolomite are derived from a contamination of the sample with adhering rock fragments. Especially the phase association of quartz and feldspar(s) is diagnostic for sand as aggregate which is usually added to (hydraulic) lime mortars.

The typical fabric of the (hydraulic) lime mortar to be observed in a thin section under a polarising light microscope consists of a more or less close packing of aggregate grains (mostly quartz and feldspar) with a filling of the interstices by calcite (figure 14). Depending on the grain shape and grain size distribution of the aggregate particles packings with pore volumes between 25 and 50 % corresponding to binder/aggregate ratios of 1:3 to 1:1 are observed. The shape of the sand grains reveals whether the sand comes from a sand pit or was produced by crushing silicate rock material. Rounded shapes are typical for natural sand grains transported by water or wind over long distances while angular shapes point either to artificially crushed rock material or rock debris transported over very short distances.

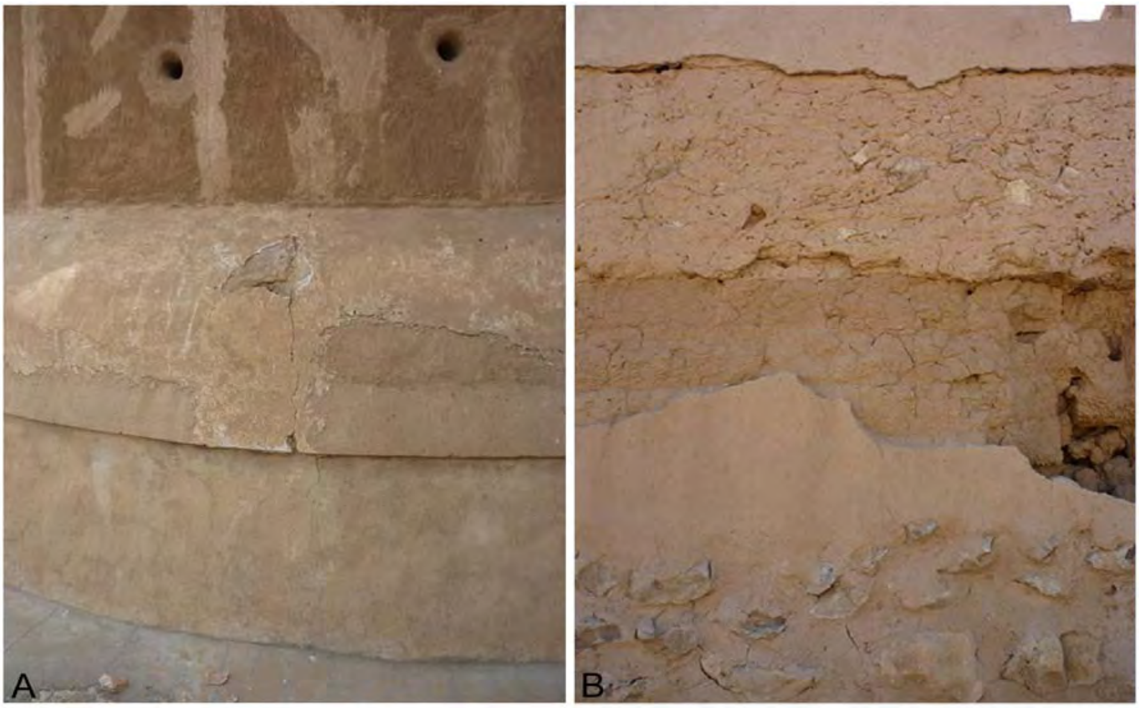

**Figure 13: Sampling localities at (A) Al Zubarah fort and (B) Al Rikiyat fort (hydraulic) lime based mortars**

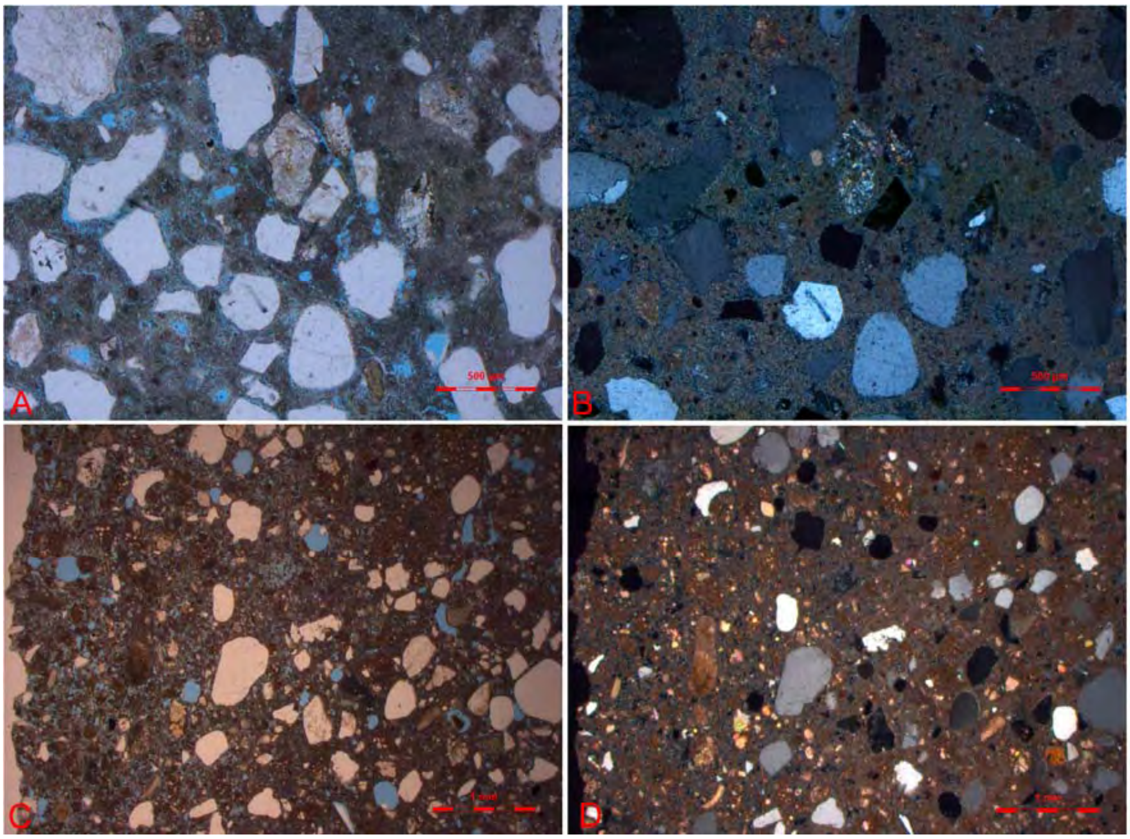

**Figure 14: Thin section photographs of (hydraulic) lime mortars from Al Zubarah fort (A,B) and Al Rikiyat fort (C, D).**

A, C: Plane-polarized light. Quartz grains embedded in calcitic matrix.

B, D: Crossed polars. Same frames as A, C

**Part 3: Development and testing of repair mortars**

# 6 Introduction

The present state of most of the exposed walls at Al Zubarah city requires urgent restoration measures in order to avoid a situation in which the restoration is replaced by reconstruction work which could interfere with the authenticity of the site. The necessary restoration work is quite a challenge due to the dilapidated state of many building stones and most of the wall mortar which in many places seems to be non-existent. The ubiquitious presence of halite (NaCl) and the hot and dry climate during the summer months are further problems to be dealt with. The ideal mortar should quickly develop a sufficient strength and show a high resistance against salt attack. Observations on the results of earlier restoration work with cement mortars and knowledge of the historic building materials prompted experiments with natural hydraulic lime and anhydrite mortar.

# 7 Natural hydraulic lime (NHL) mortar

Natural hydraulic lime as binder combines the advantages of low alkali contents and comparatively quick hardening due to its content of cement clinker phases which are formed by the burning of marly limestone. The strength of the hardened mortar is considerably lower than that of cement mortars and goes much better with the softness of most of the building stones (with the exception of the dolomitic limestone) than cement mortars. Under the prevailing weather conditions pure lime mortars on the other hand have the risk of falling dry too quickly before the carbonation of the slaked lime is complete and the strength typical for this material developed.

The standard mixture for a NHL mortar contains 1 volume part binder and 3 volume parts aggregate. The use of sand from the beach as it is cannot be recommended because it contains at least 1 – 2 mass% sodium chloride. This salt content, however, can be lowered to about one third of the original content by washing the sand with the double volume of salt-free water. Alternatively, commercially available quartz sand can be used as aggregate. A mixture of washed beach sand containing shells and gastropods and quartz sand is probably best suited for the production of a NHL mortar which matches best with the colours of the building stones.

In order to overcome the problem of premature drying about 1 – 2 mass% tylose is added to the mortar. Tylose serves to retain the water in the mortar paste. The effect of tylose in the mixture can best be studied when water is added to the dry mixture of binder and aggregate: 2 mass% tylose in the mixture almost doubles the amount of water that can be added to get a workable mortar.

Prior to the application on site, test runs were done with NHL and anhydrite in the laboratory. The experiments with NHL were carried out with Otterbeiner Hydradur while AB 30, a product of the Südharzer Gipswerk GmbH, was chosen as **a**nhydrite **b**inder. For the determination of the compressive strength and elastic modulus prisms of 4 x 4 x 16 cm³ in size were prepared and tested after 9 days of hardening. The test results are presented in table 4. The strength of the AB 30 mixture is much too high and later in the field aggregate/binder ratios of

## 7.1 Laboratory tests

The laboratory tests were done with standard prisms 4 x 4 x 16 cm³ in size. Young's modulus E was calculated from the length of the prism l and the measured values of the bulk density $\rho_b$ and resonance frequency $\nu_0$ of the dilatation wave ($E = v_D^{2} * \rho_b$, $v_D = 2l\nu_0$).

**Table 5: Physical parameters of NHL mortars (after 9 days of hardening)**

| Sample | Composition | Density [g/cm³] | Young's modulus [kN/mm²] | Compressive strength [N/mm²] |
|---|---|---|---|---|
| 1 | 1 vol. part NHL 5, 3 vol. parts aggregate, 1 vol. part water | 1,45 | 1,8 | 1,5 $^{+)}$ |
| 2 | 1 vol. part NHL 5, 3 vol. parts aggregate, 2 vol. parts water, 2 mass% tylose | 1,44 | 1,8 | 1,5 $^{+)}$ |

$^{+)}$ The compressive strength after 28 days of hardening ranges between 3 – 5 N/mm².

## 7.2 Field tests

In the area of consolidation at the Northern end of Al Zubarah city several test fields were prepared with NHL mortar (figure 15) and the state of the mortar studied after a period of about six month. (The test fields at the wall of tower no. 8 which were carried out in February 2011 are not considered here because the time span between preparation and sampling would have been too short for the observation of noticeable effects.) The first test was scratching the mortar with a finger nail or the rubbing it between two fingers. Already this simple test showed that the NHL mortars had developed good strength and did not fail. Small samples were taken from the test fields and prepared for examination by X-ray diffractometry and optical microscopy.

**Table 6: NHL mortars from the test areas at the tower structure (after 6 month of exposure)**
(see documentation by M. Kinzel, June 2010)

| Sample No. | Composition $^{+)}$ | | | | | Phase composition |
|---|---|---|---|---|---|---|
| | Sand | | | NHL | Tylose | |
| | A | B | C | | | |
| II | - | - | 3 | 1 | - | quartz, calcite, plagioclase, K feldspar |
| XI | 1 | 1 | 1 | 1 | 1 | calcite, quartz, (halite), gypsum, Mg calcite II, aragonite, plagioclase, anhydrite |
| XII | - | - | 1 | 1 | 1 | quartz, calcite, K feldspar, (halite), plagioclase |
| XIII | ? | ? | 1 | 1 | 1 | Mg calcite II, calcite, quartz, aragonite, dolomite, plagioclase, (halite), gypsum |

$^{+)}$ Sand and NHL (Otterbeiner Hydradur NHL 5) in volume parts, tylose in mass%

The X-ray diffractograms of all NHL mortars with quartz sand as aggregate are marked by the presence of diffraction peaks for quartz, calcite, and feldspars (K feldspar and/or plagioclase). Examples for this type of mortar are the samples II and XII. If shell sand which is derived from beachrock material is added additional peaks for Mg calcite II and aragonite appear (sample XI). Halite is preferably present in samples with shell sand through which it is introduced to the mortar. Diffraction peaks for gypsum and anhydrite occur if the samples are contaminated with small amounts of historic wall mortar or plaster.

The investigation of a thin section of the NHL mortar evealed quartz grains and fossil debris bonded by bridges of calcite cement (figure 16). The packing of the quartz grains is very loose and practically no point contacts between quartz grains are observed. The pore size is in the order of the particle size. Due to the loose packing of aggregate particles and the highly porous structure the investigated sample will not have a compressive strength higher than 2 N/mm². The large pore space results in a large storage capacity for salts in the mortar. A higher strength will be achieved if the packing of aggregate particles is made tighter and the whole fabric less porous.

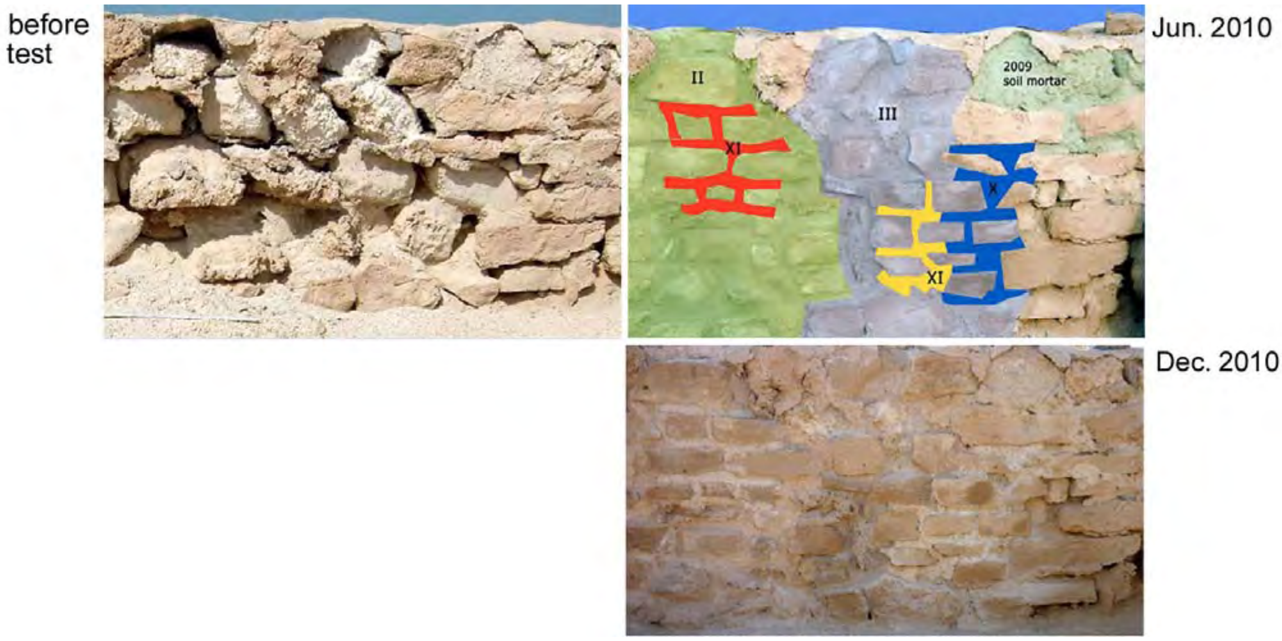


**Figure 15: Test fields with NHL mortar at Eastern part of tower structure**
(Roman numerals refer to sample numbers in table 6)

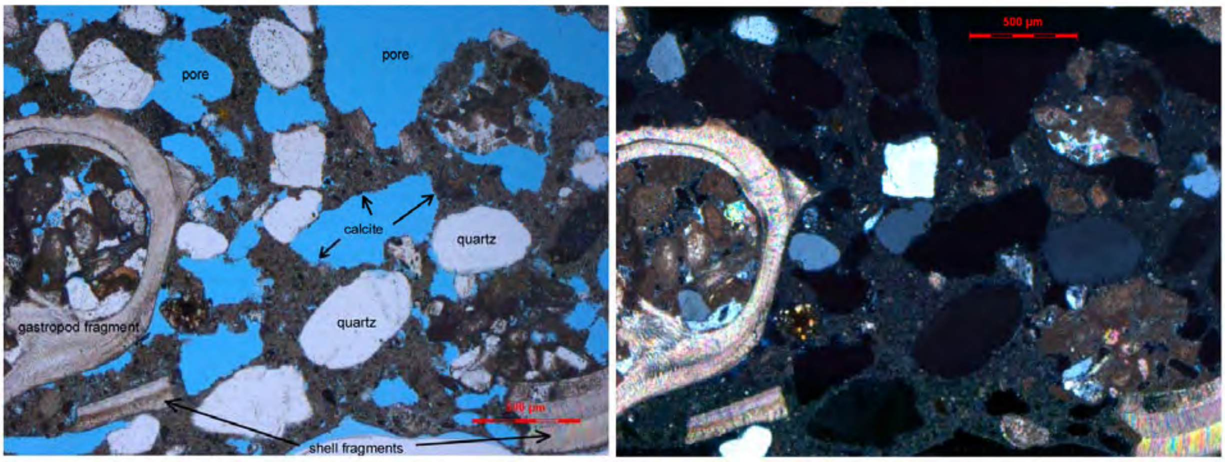


**Figure 16: Fabric of NHL mortar with a mixture of quartz and shell sand as aggregate.**
Note the fairly large pores and the binding calcite between quartz grains and fossil debris. Left: Plane-polarized light, right: crossed polars

## 8 Anhydrite mortar

The use of anhydrite mortar in the past is clearly demonstrated by the many remnants and fragments of plaster in the ruined buildings of Al Zubarah city. The investigation result for a wall mortar sample from the mosque at Freha indicates that anhydrite was also used as binder in wall mortars. Therefore field tests were carried out with modern anhydrite mortar to test its performance. So far, anhydrite mortar was used for jointing and plastering but it should also be tested as wall mortar. The hardening of anhydrite mortar requires more time than that of hydraulic lime mortar and there is a greater risk of falling dry in a hot dry desert climate before the process of hardening is complete.

Therefore precautions such as watering and covering freshly worked sections have to be taken in order to avoid that. Anhydrite mortar for plastering the walls may play an important role because the general poor quality of the building stones makes a protective coating of the walls necessary if sustainability of the conservation efforts is aspired.

## 8.1 Laboratory tests

The same procedures described under 7.1 were employed to determine the physical parameters given in table 7. Further experiments showed that the compressive strength of the anhydrite mortar can be controlled by the binder/aggregate and water/binder ratios and fixed to any desired value accordingly.

**Table 7: Physical parameters of AB 30 anhydrite mortar**

| Sample | Composition | Young's modulus [kN/mm²] | Compressive strength [N/mm²] |
|---|---|---|---|
| **1** | **4 vol. parts AB 30, 1 vol. part sand, 1 vol. part water** | **22,4** | **33,6** |

## 8.2 Field tests

So far, field tests with four different anhydrite mortars (?, QMA, HAP, AB 30) for jointing and plastering were carried out at a tower construction in the area of consolidation and at the wall of tower no. 8. QMA is a local anhydrite while HAP and AB 30 are produced by the Südharzer Gipswerk GmbH in Germany. The acronym HAP stands for "**h**istoric **a**nhydrite **p**laster" while AB stands for "**a**nhydrite **b**inder" and **30** refers to the compressive strength (≥ 30 N/mm²) of the hardened mortar.

**Table 8: Anhydrite mortars from the test areas at the tower structure in the area of consolidation** (after 6 month of exposure; see documentation by M. Kinzel, June 2010) **and tower no. 8**

| Sample | Composition [1] | | | | | | | | Application for | Phase composition |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sand | | | Anhydrite | | | NHL | Tylose | | |
| | A | B | C | QMA | HAP | AB30 | Hydradur | | | |
| IV[2] | - | - | 2 | 1 | - | - | - | - | jointing | quartz, plagioclaase, gypsum, anhydrite, K feldspar, calcite |
| IX[2] | - | - | 2 | 1 | - | - | - | - | jointing | K feldspar, quartz, anhydrite, gypsum, calcite |
| X[2] | 1 | 1 | 1 | 1,5 | - | - | - | - | jointing | quartz, gypsum, anhydrite, K feldspar, calcite, (halite) |
| F[3] | - | - | 10 | 4 | - | - | 1 | 0,1 | plastering | quartz, gypsum, calcite, K feldspar, anhydrite, plagioclase |
| G[3] | - | - | 6 | 4 | - | - | 1 | 0,1 | plastering | quartz, gypsum, K feldspar, plagioclase, calcite, anhydrite |
| HAP | - | - | 2 | - | 1 | - | - | - | plastering | anhydrite, quartz, plagioclase, calcite, K feldspar, (halite), gypsum |
| AB | - | - | 2 | - | - | 1 | - | - | plastering | quartz, anhydrite, K feldspar, plagioclase, calcite, gypsum |

[1] Sand, anhydrite and NHL (Otterbeiner Hydradur NHL 5) in volume parts, tylose in mass%

[2] Roman numerals refer to labelling by M. Kinzel

[3] Labelling refers to protocol by P. Hofmann

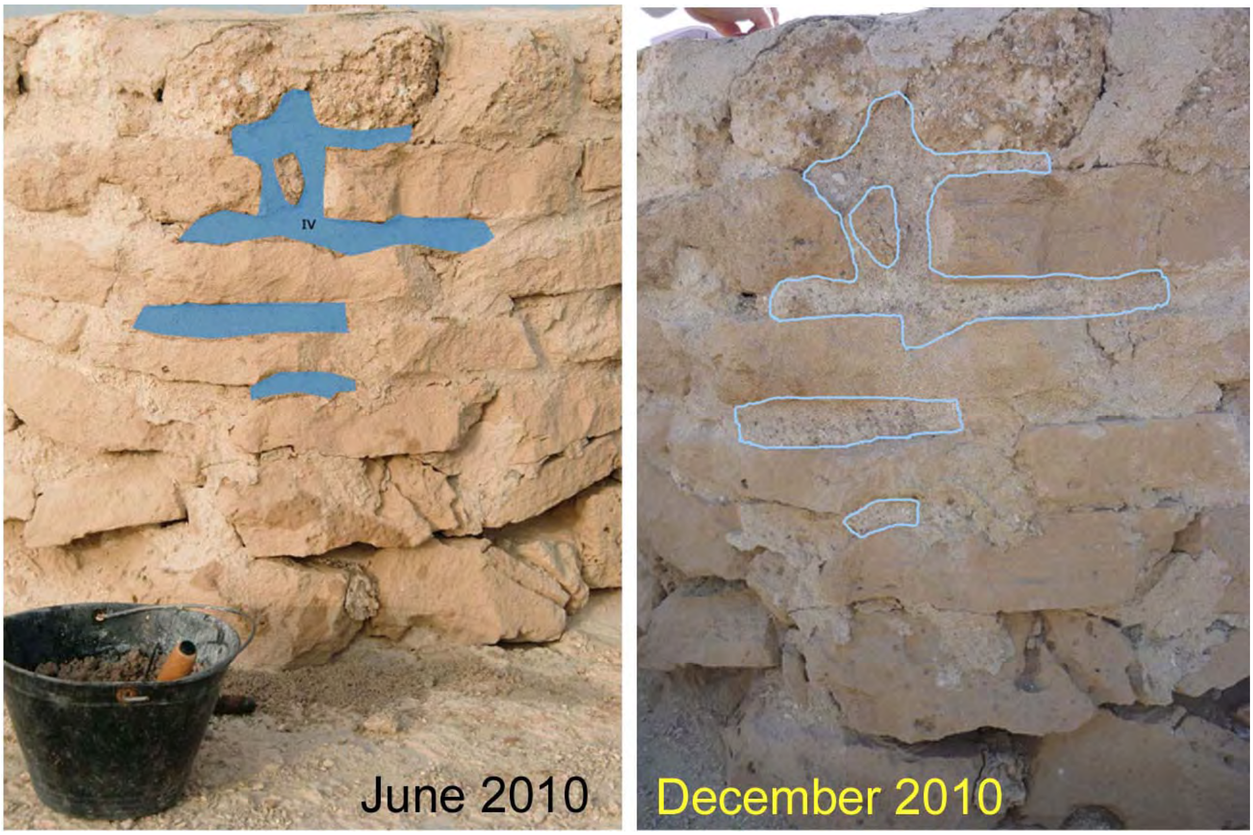


**Figure 17: Test field IV with anhydrite mortar for jointing at NE corner of tower structure**
(Roman numeral refers to sample number in table 8)

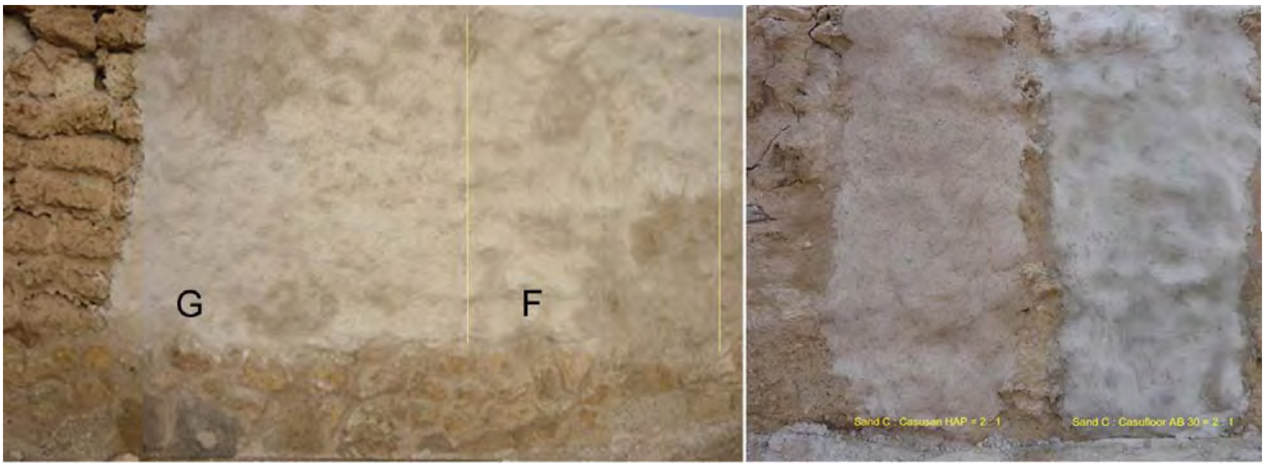


**Figure 18 Test fields with anhydrite mortar for plastering at wall of tower no. 8**
(February, March 2011)

While the first three tests (IV, IX, X) were done in June 2010 with an anhydrite of unknown specification the following two tests (F, G) were made in February 2011 with QMA anhydrite and NHL added as activator. For two further tests in March 2011 the ready-made anhydrite binders HAP and AB 30 from the Südharzer Gipswerk GmbH in Germany were used. The samples were about 270, 30 and 10 days old at the time of sampling.

For the assessment of the hydration reaction and quality of the mortar the quotient

$$\frac{I_{(020)Gypsum}}{I_{(020)Gypsum} + I_{(020)Anhydrite}}$$ was used.

If the reaction is complete then there should be no more X-ray diffraction peaks of anhydrite in the X-ray diffractogram. 1 signifies complete, 0 no reaction at all. Since the performance of an anhydrite mortar is related to the degree of anhydrite conversion, the quotient in a way reflects its quality. A comparison of quotients, however, is only meaningful if the mortars compared had sufficient time to react. As mentioned above, the reaction time for the samples F, G, HAP, and AB is definitely too short for a conclusive assessment of the quality. Table 9 lists the quotients for historic anhydrite mortars and the anhydrite mortars of the field tests.

**Table 10: (020) gypsum and anhydrite diffraction peak intensity ratios of anhydrite mortars**

| Sample | Quotient | Sample | Quotient |
|---|---|---|---|
| 1 | 1,00 | X | 0,50 |
| 2 | 1,00 | F | 0,66 |
| 4 | 0,98 | G | 0,77 |
| 5 | 0,97 | HAP | 0,07 |
| IV | 0,50 | AB | 0,04 |
| IX | 0,39 | - | - |

As would be expected the highest values are exhibited by the historic anhydrite mortars. They are at least two hundred years old and still in a good condition with respect to their strength. The quotients for the mortars of the second group (IV, IX, X) which are about 270 days old fall behind the quotients for the third group (F, G) which were only 30 days old at the time of sampling. The anhydrite used for the tests in the second group was of unspecified quality and had probably exceeded the expiry date. The quotients for the third group are very promising and show the direction which further tests should follow. By all means tests should be made with mixtures of anhydrite and slaked lime. As the reaction time for the samples of the fourth group (HAP. AB) is too short for a meaningful evaluation of the X-ray diffractogram this will be postponed to December 2011 after the investigation of new samples from the two test fields.

## 9 Consolidation experiments with nano-lime solutions

A lot of the building stones in the city walls of Al Zubarah, especially the beachrocks, are in a poor state of preservation and should be either replaced or consolidated. The porous structure of the beachrocks allows an impregnation with solidifying fluids. A test was made with a colloidal solution of portlandite in ethanol (Ziegenbalg et al. 2010), the so-called nano-lime solution. Portlandite, ($Ca(OH)_2$, reacts with atmospheric carbon dioxide to form water and calcium carbonate which is supposed to cement the disrupted rock fabric.

$$\mathbf{Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O}$$

Figure 19 shows a dilapidated wall section with two beackrocks treated with differently concentrated nano-lime solutions. The sample for investigation by X-ray diffraction and optical microscopy of a thin section was taken from the red-marked stone which was treated with the higher concentrated solution so that the expected effect would be more pronounced and detectable.

**Table 10: Phase composition of beachrock sample treated with nano-lime solution**

| Sample | Locality | Phase composition |
|---|---|---|
| 2b E25 | Area of consolidation | Mg calcite II, Mg calcite I, dolomite, aragonite, quartz, K feldspar, (halite),gypsum |

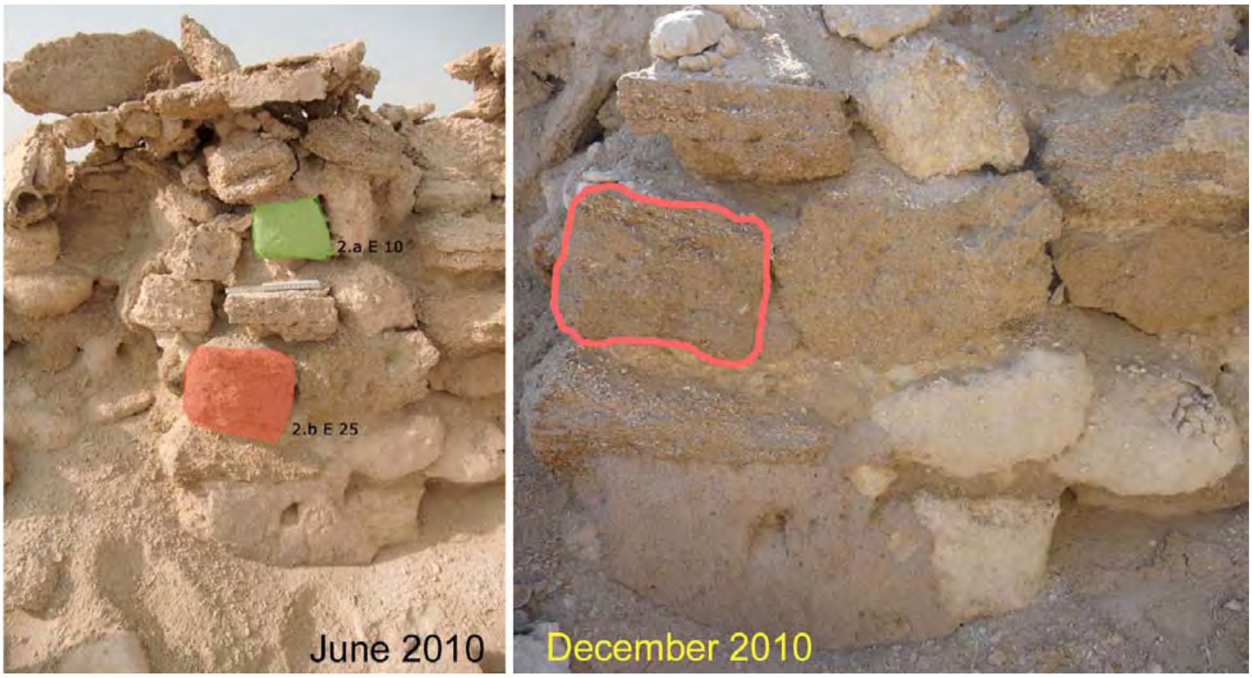


**Figure 19: Consolidation tests with nano-lime solution**

The observation that newly formed calcite is visible in the thin section of the sample but not in the corresponding X-ray diffractogram indicates that it is below the detection limit of 1 – 2 mass%. The newly formed calcite would be a stoichiometric calcite without Mg in the crystal structure. The two calcites identified in the X-ray diffractogram are Mg calcites with 14,8 (II) and 3,7 (I) mol% $MgCO_3$. As a matter of fact, figure 20 shows loosely dispersed calcium carbonate in the pore space indicating that the postulated reaction takes place. However, the amount and state of the newly formed calcium carbonate is not apt to consolidate the loose fabric. In order to achieve the desired effect either the concentration of portlandite in the solution must be increased or the impregnation of a rock must be successively repeated.

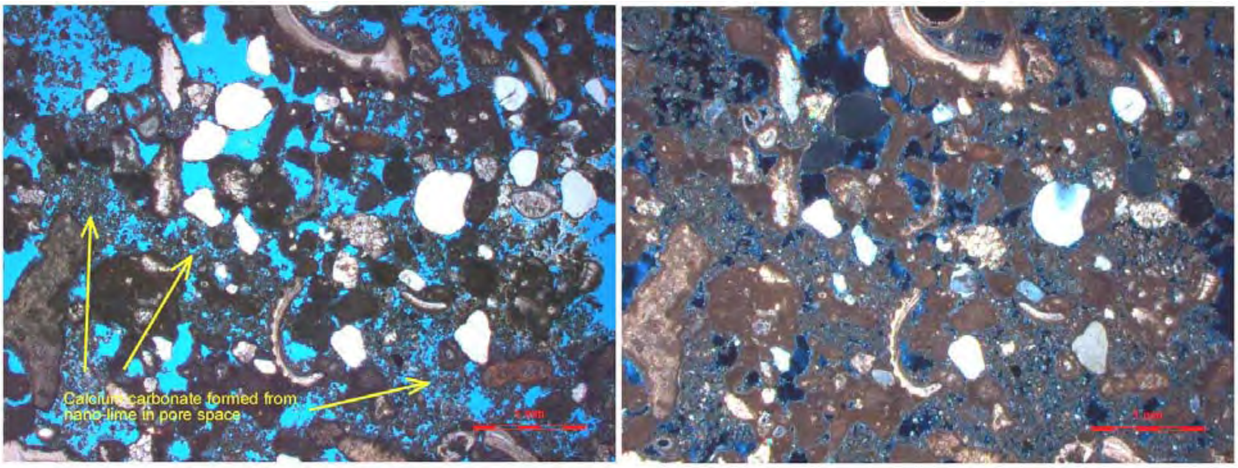


**Figure 20: Thin section photograph of beachrock sample treated with nano-lime solution.** Left side: Plane-polarized light. Porous structure of beachrock with some newly formed calcium carbonate in the pore space (yellow arrows). Right side: Crossed polars. Same frame as on the left side

## 10 References

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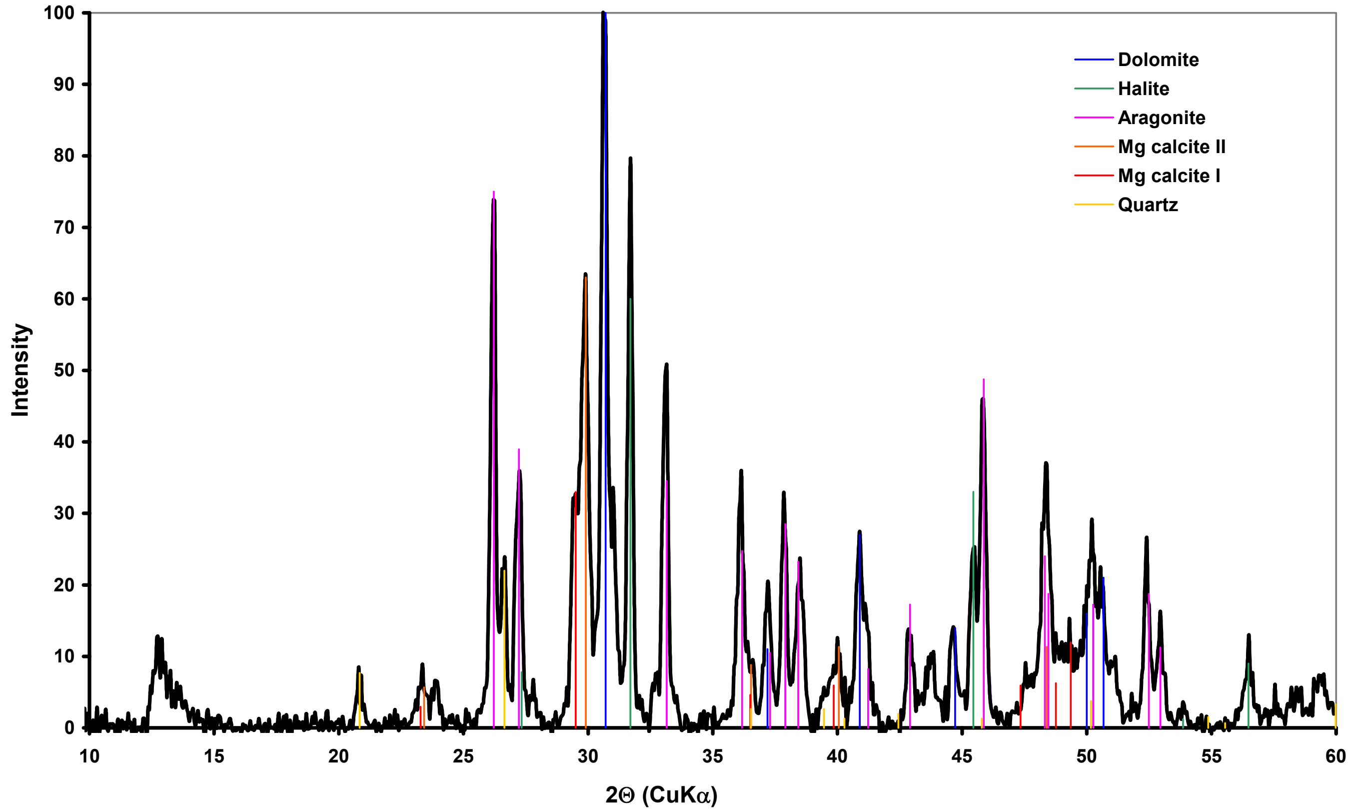
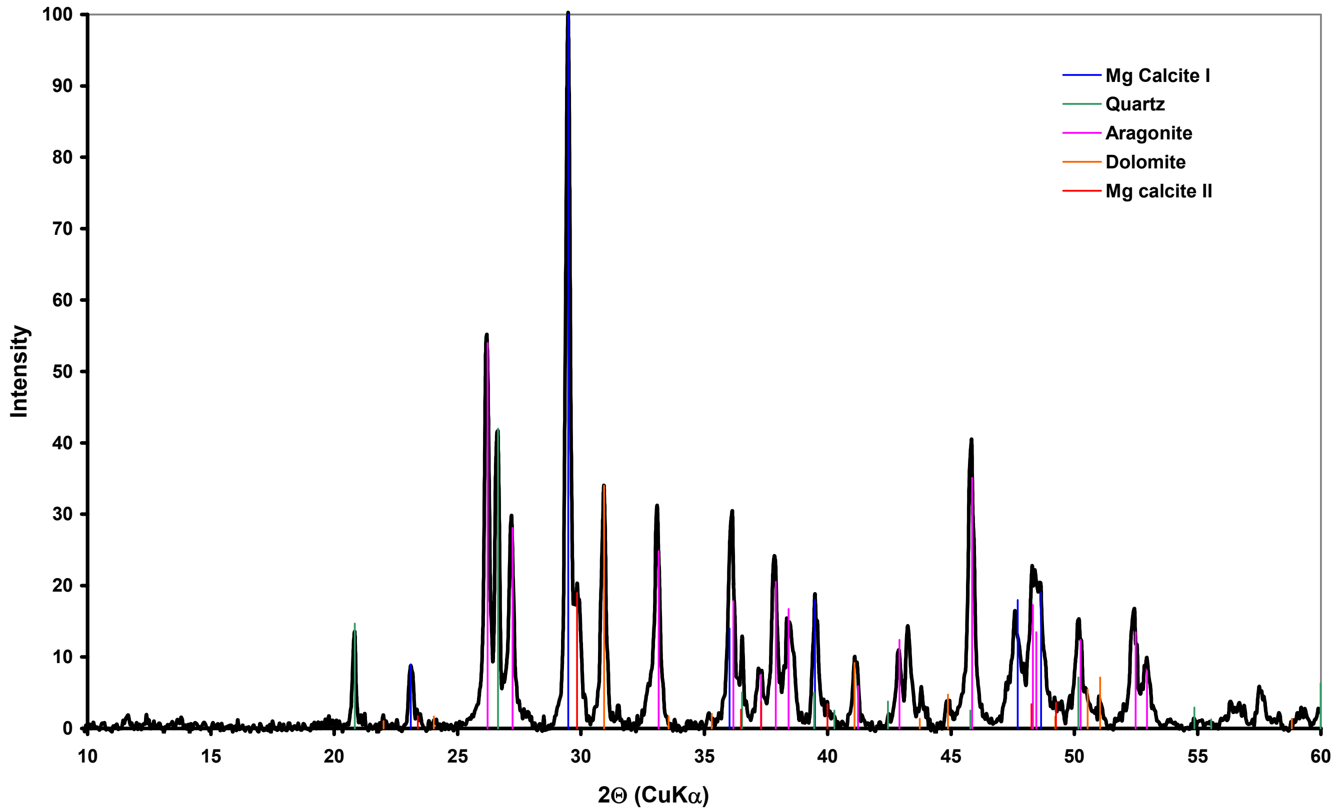
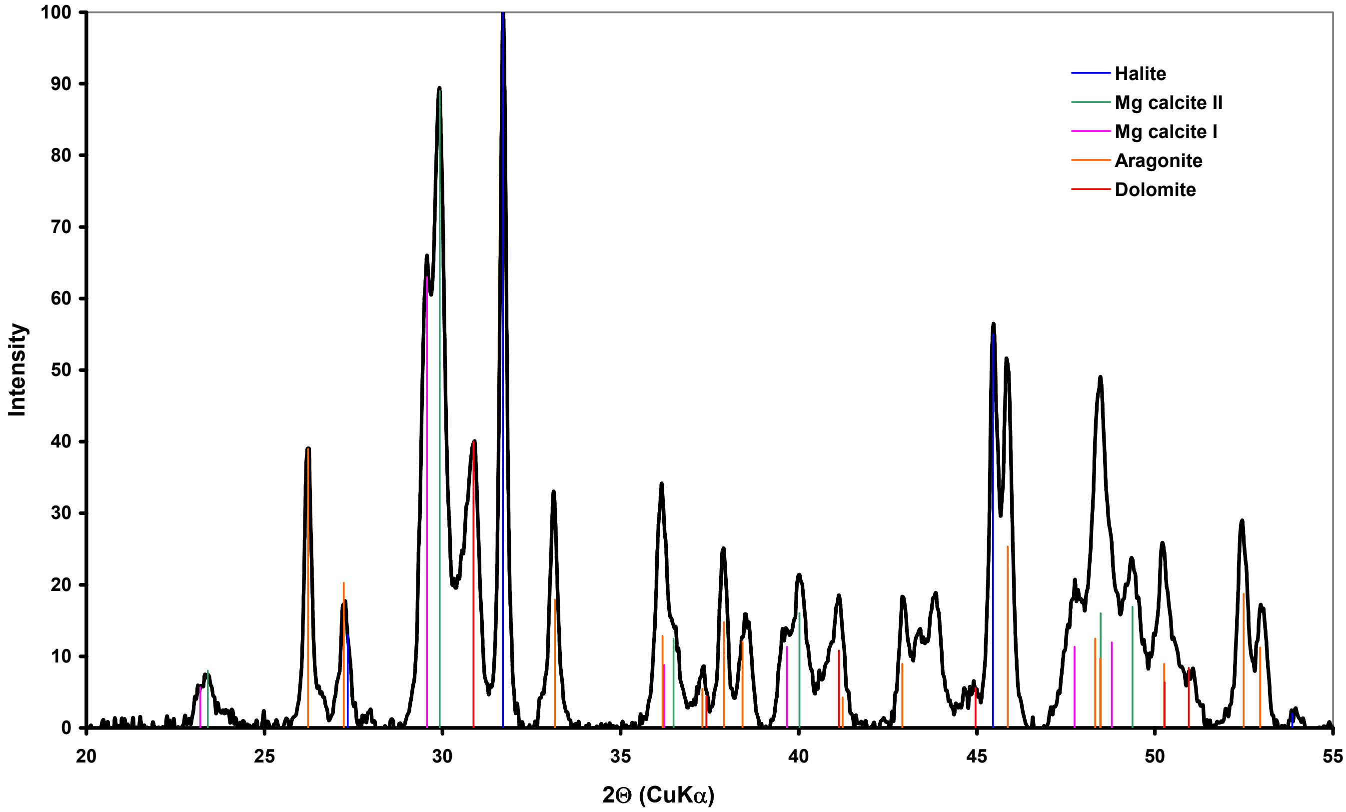
# 11 Appendix (X-ray diffraction diagrams of rocks and mortars)



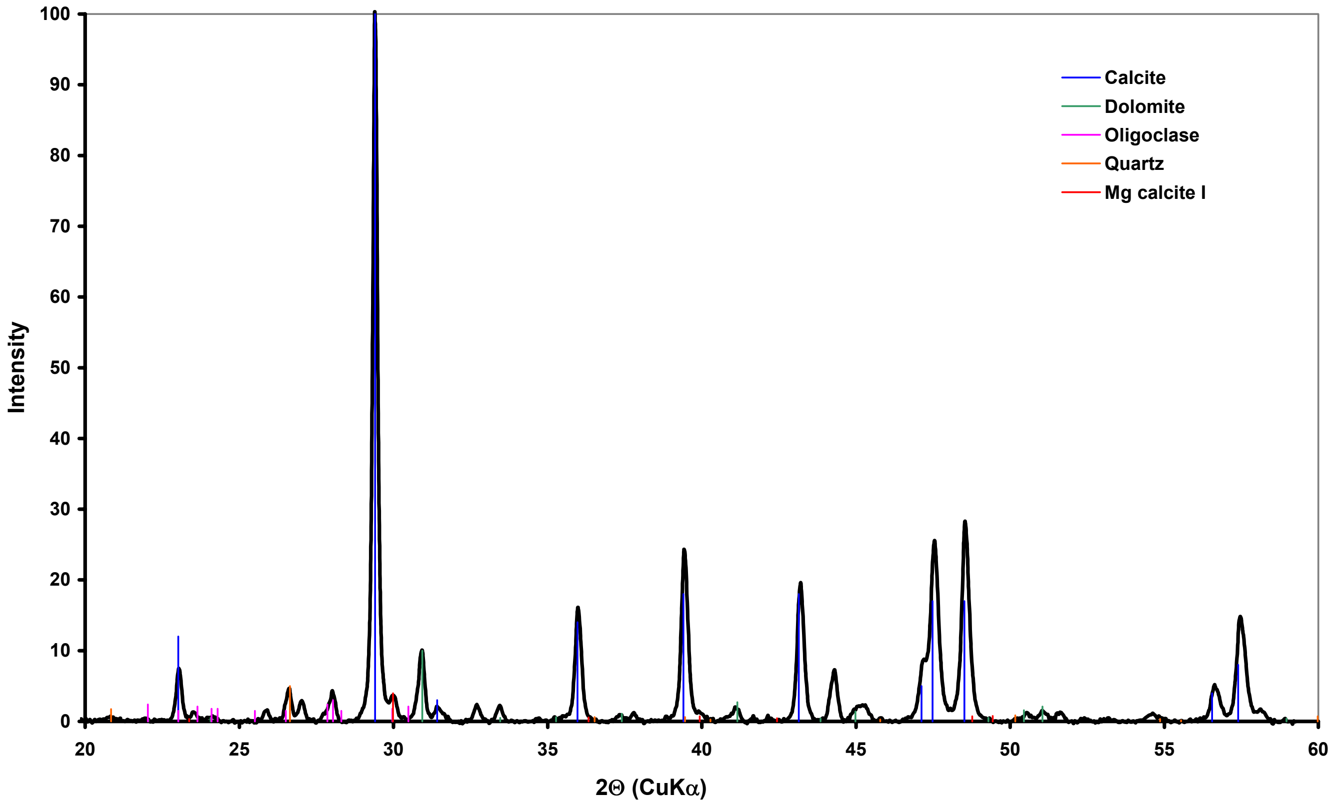

X-ray diffractogram of beachrock type I AG (silty carbonate sand with abundant bivalves)



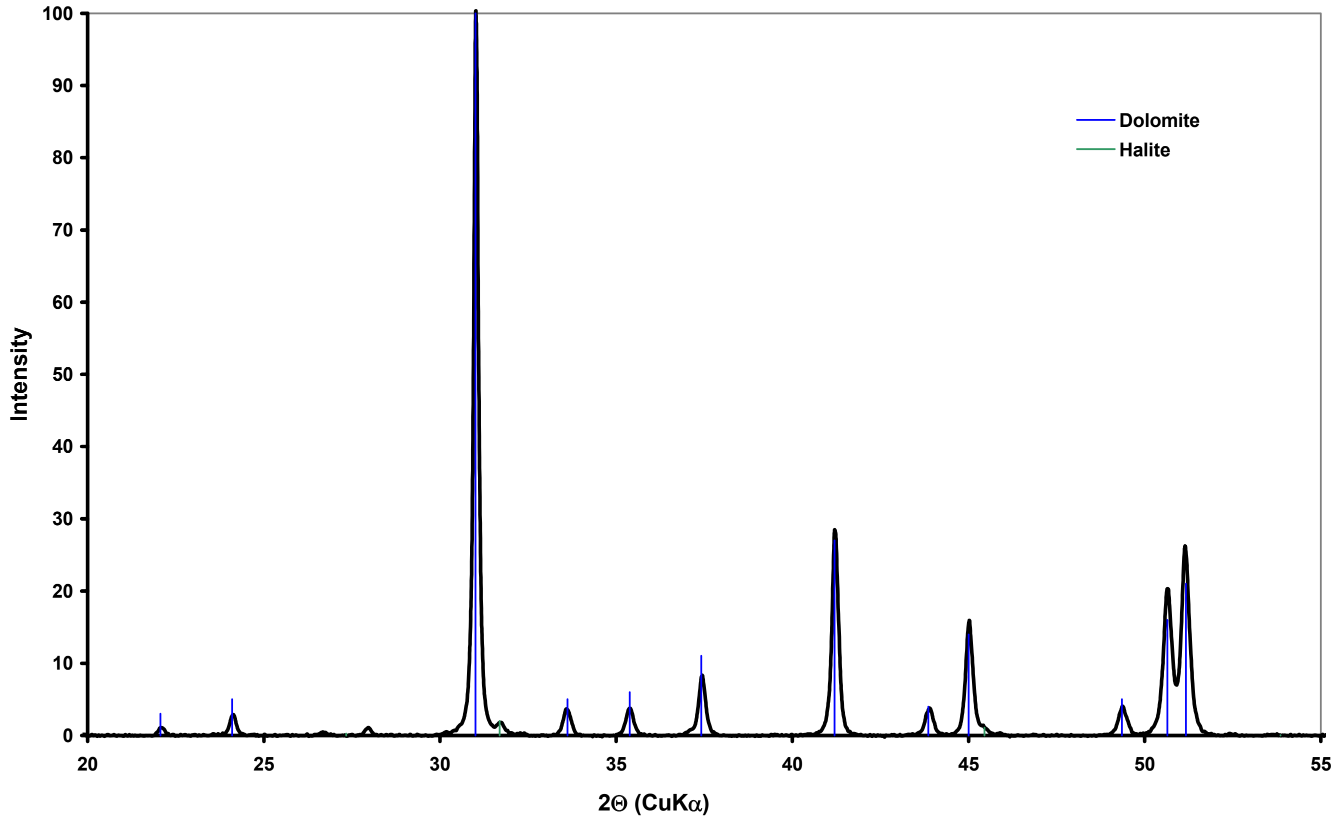

X-ray diffractogram of exposed beachrock (“table stone”; see figure 5)



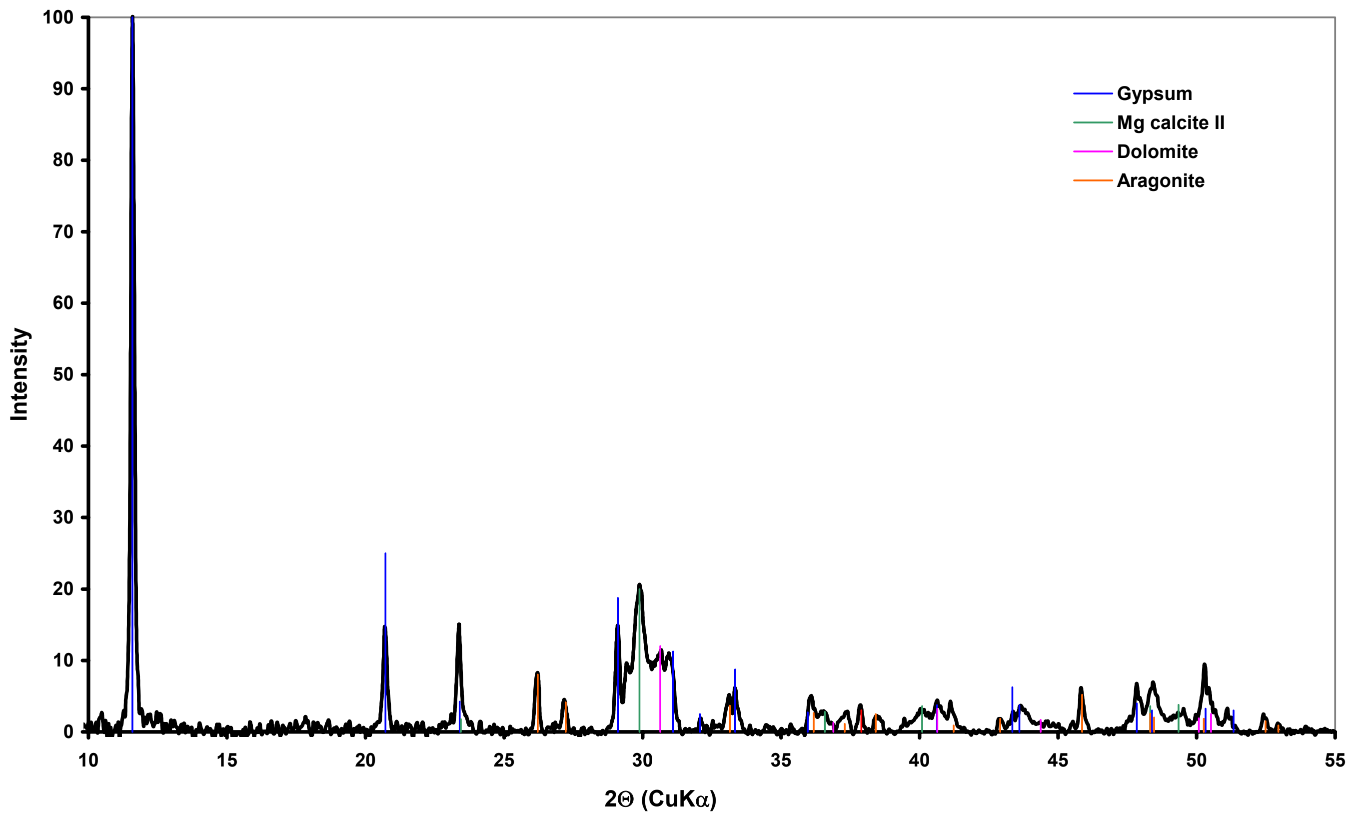

**X-ray diffractogram of beachrock type II BJ (silty carbonate sand with abundant gastropods)**



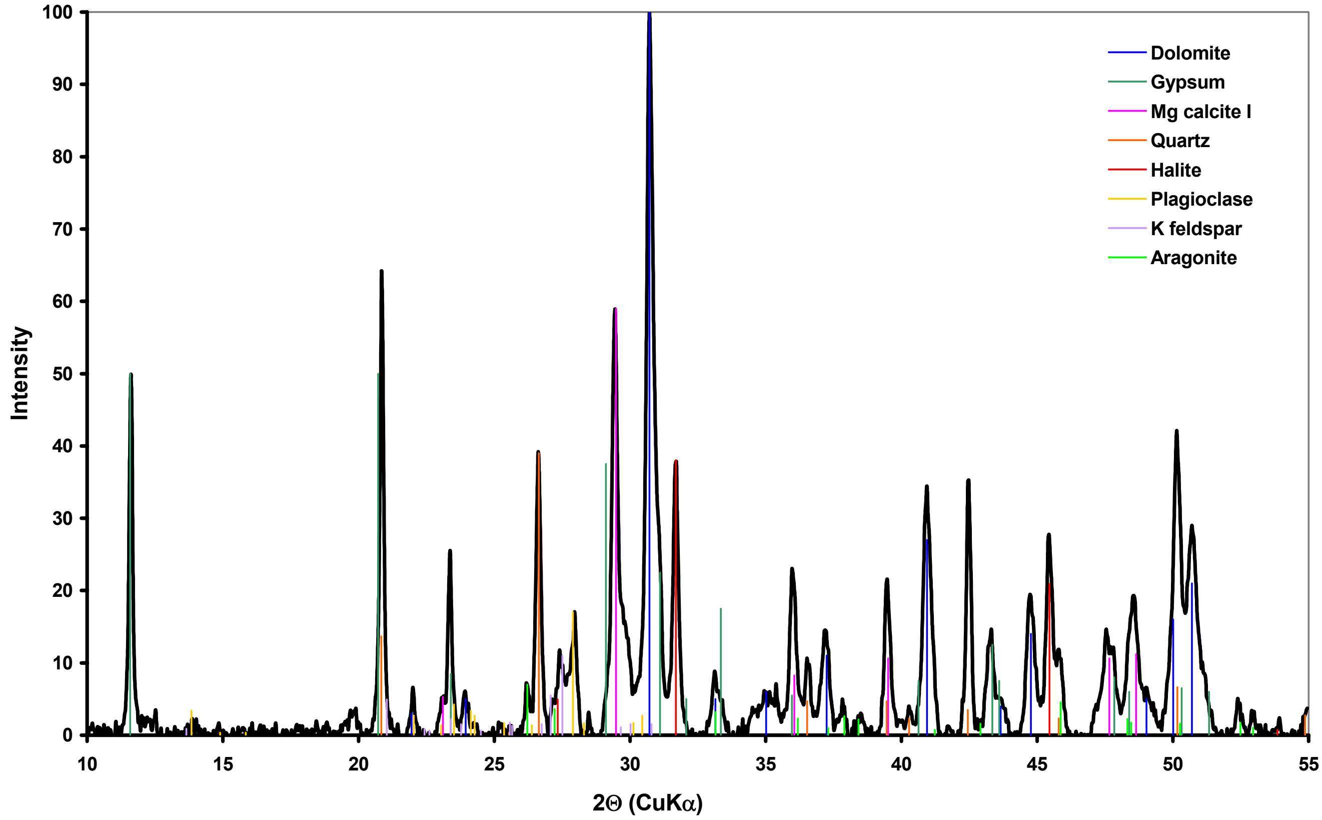

**X-ray diffractogram of aeolianite FR**



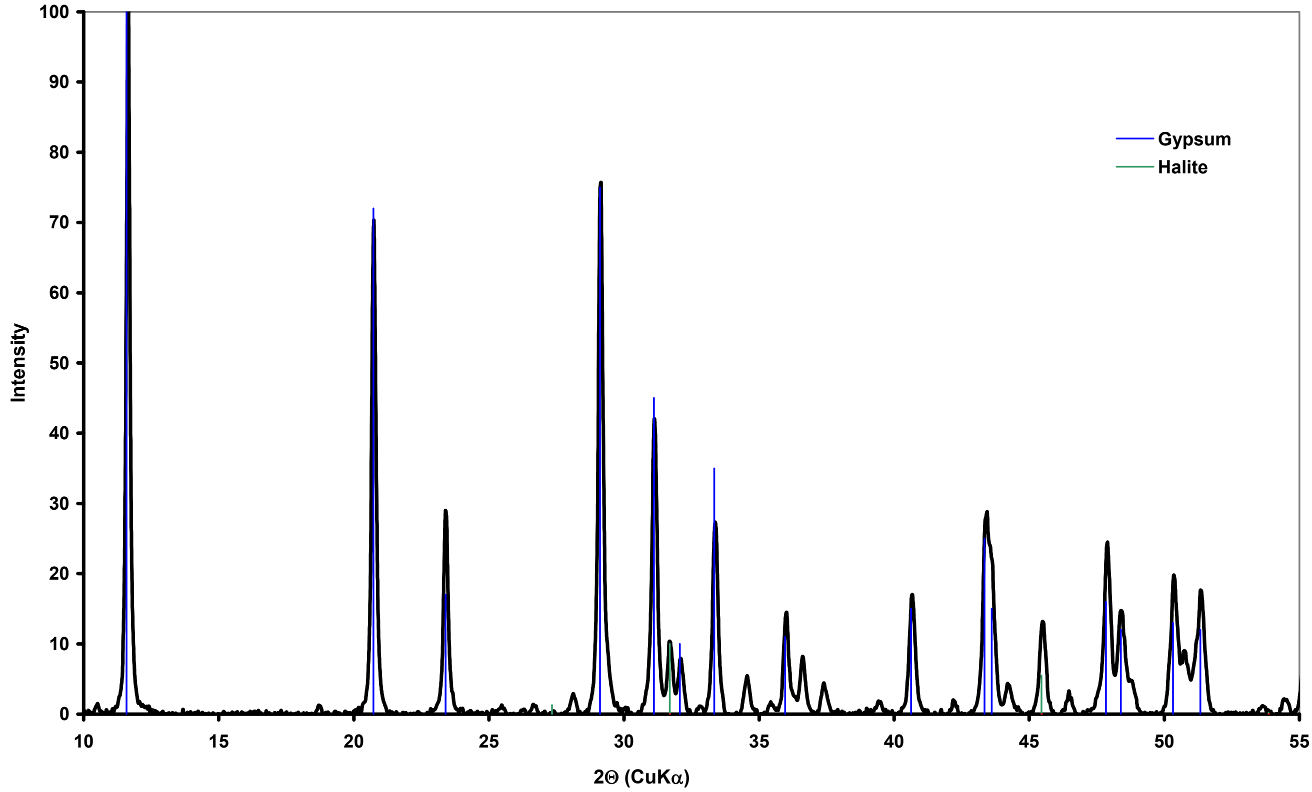

X-ray diffractogram of Dammam dolomitic limestone BI



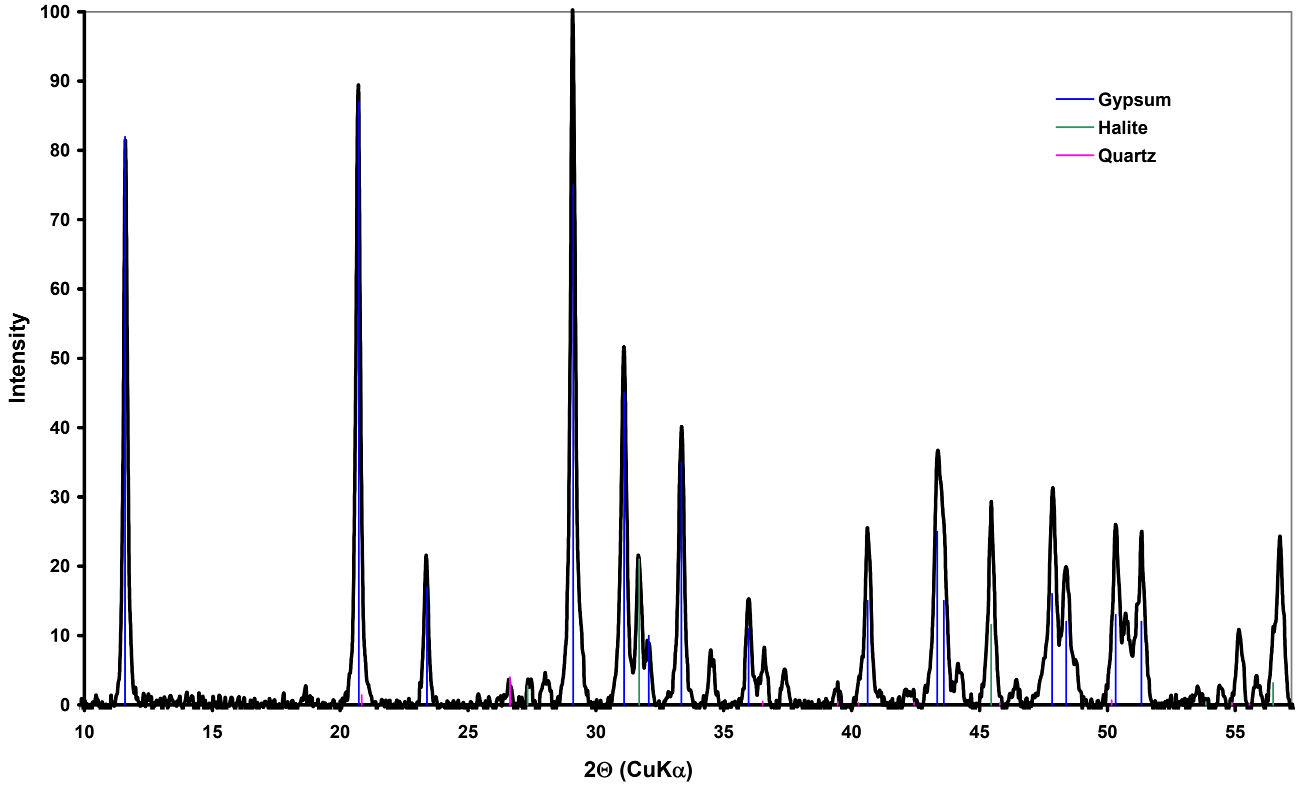

X-ray diffractogram of evaporitic mudstone (gypsum) BE



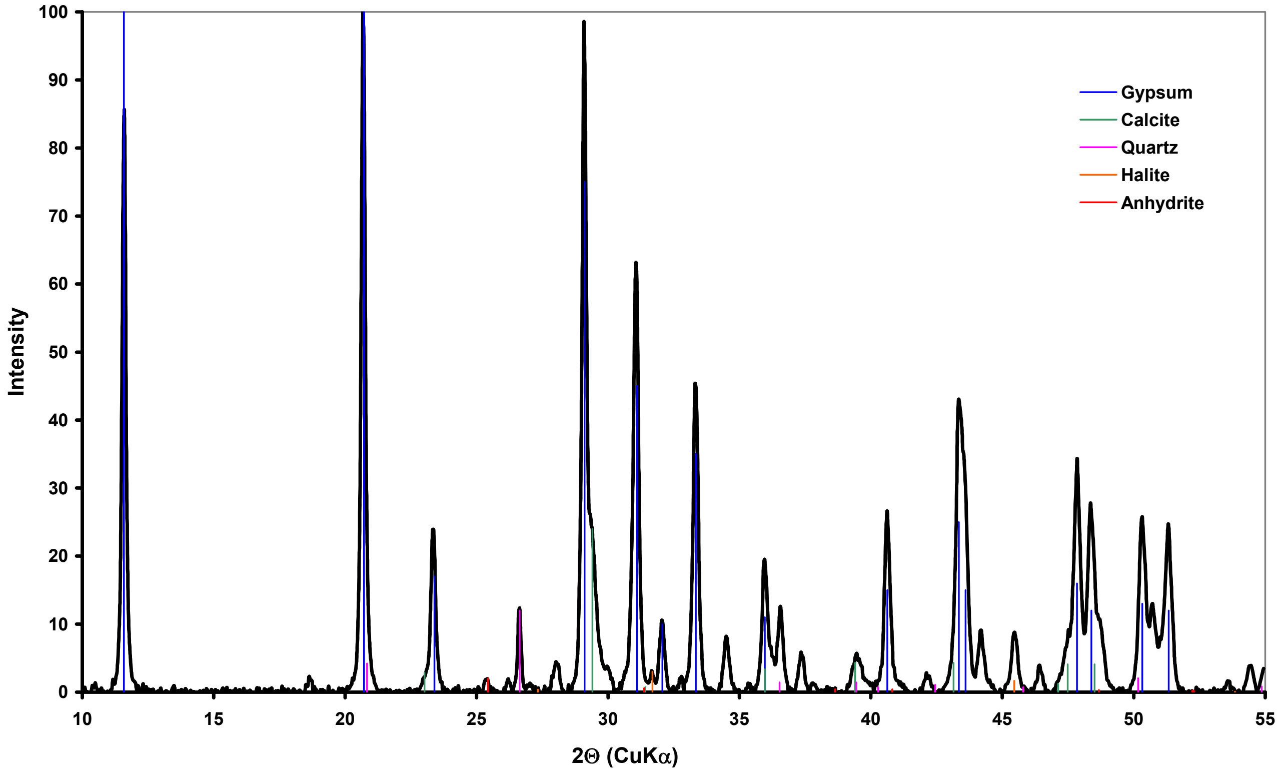

**X-ray diffractogram of wall mortar, Freha mosque (figure 12)**



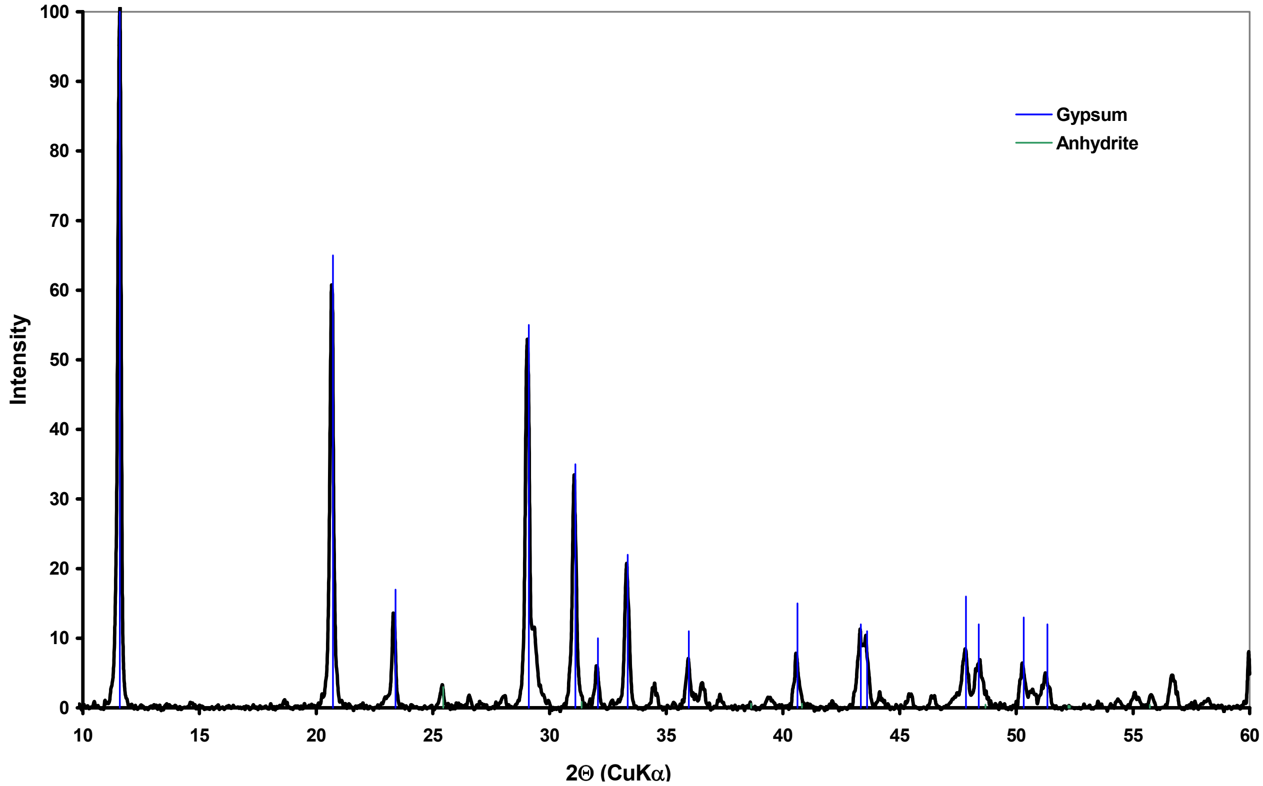

**X-ray diffractogram of wall plaster, lower layer, Freha mosque (figure 11)**



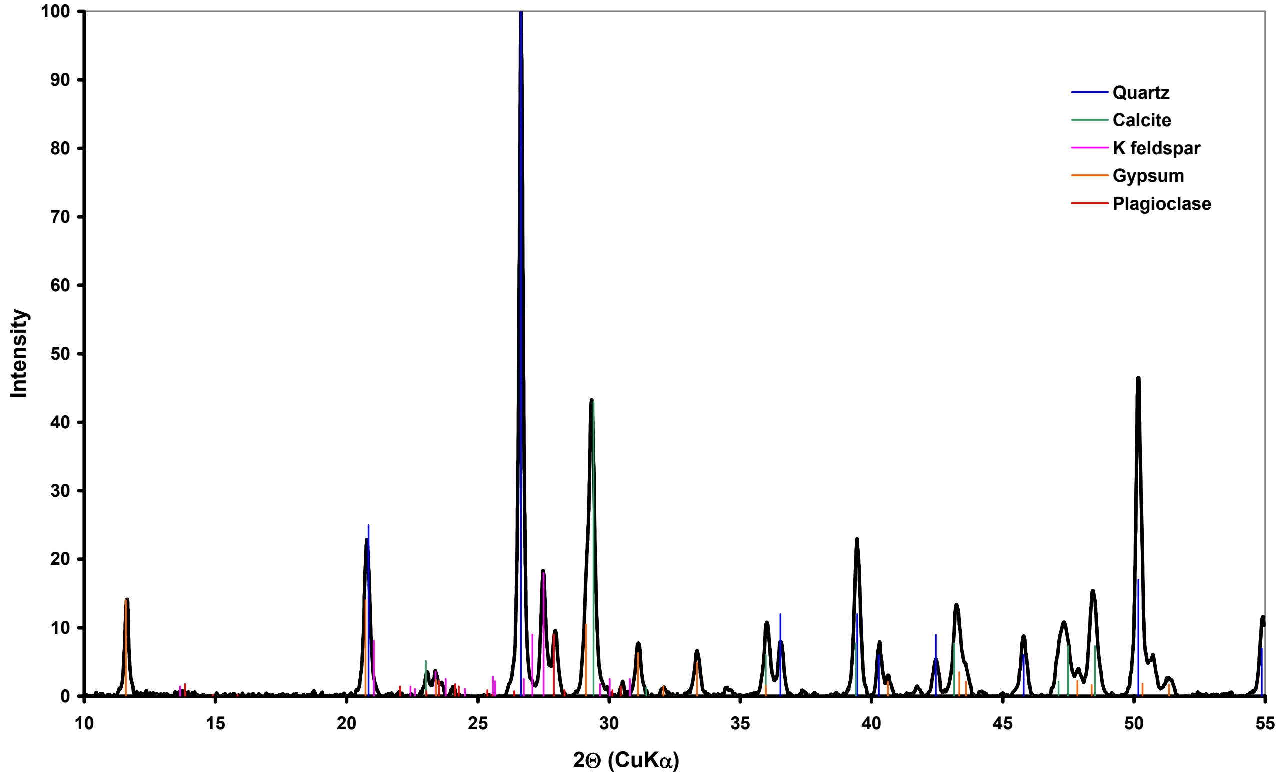

X-ray diffractogram of wall plaster, upper layer, Freha mosque (figure 11)



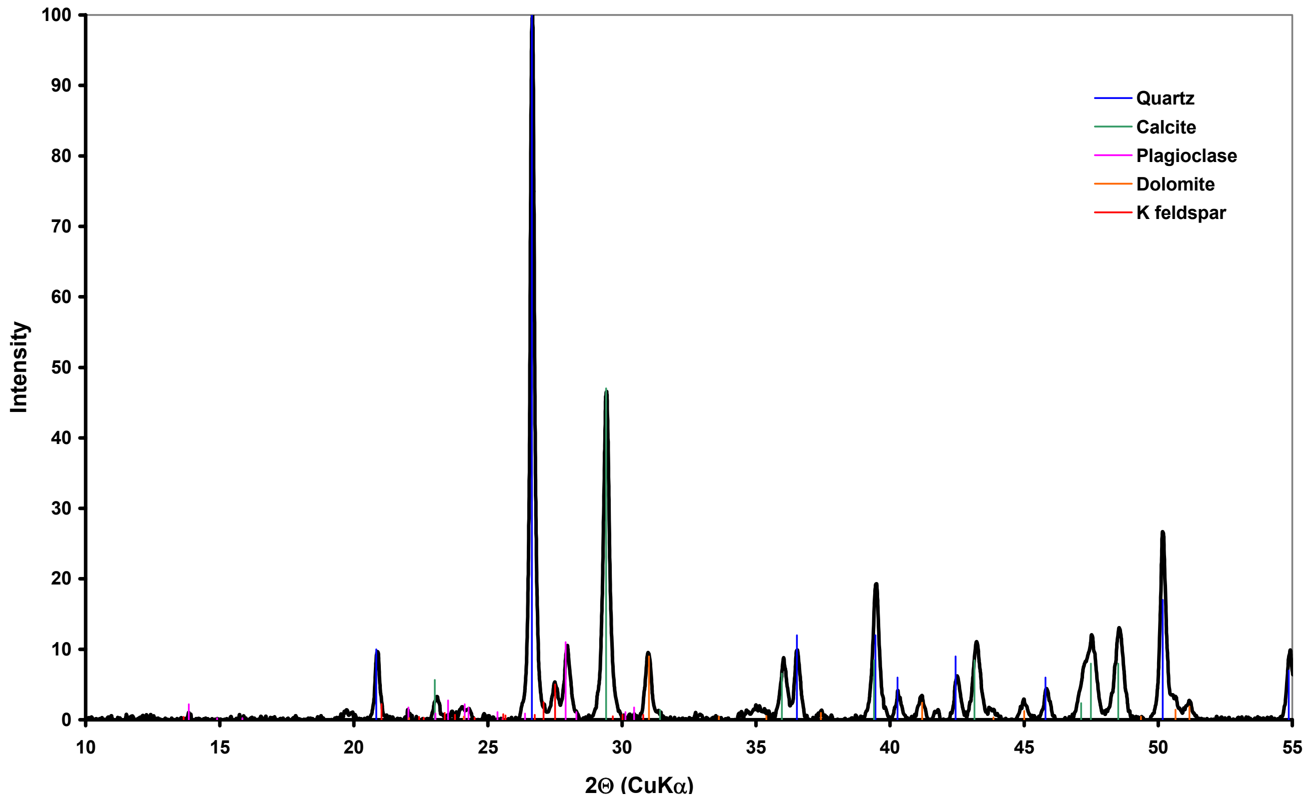

X-ray diffractogram of wall plaster, Al Zubarah city, Southfield (figure 11)



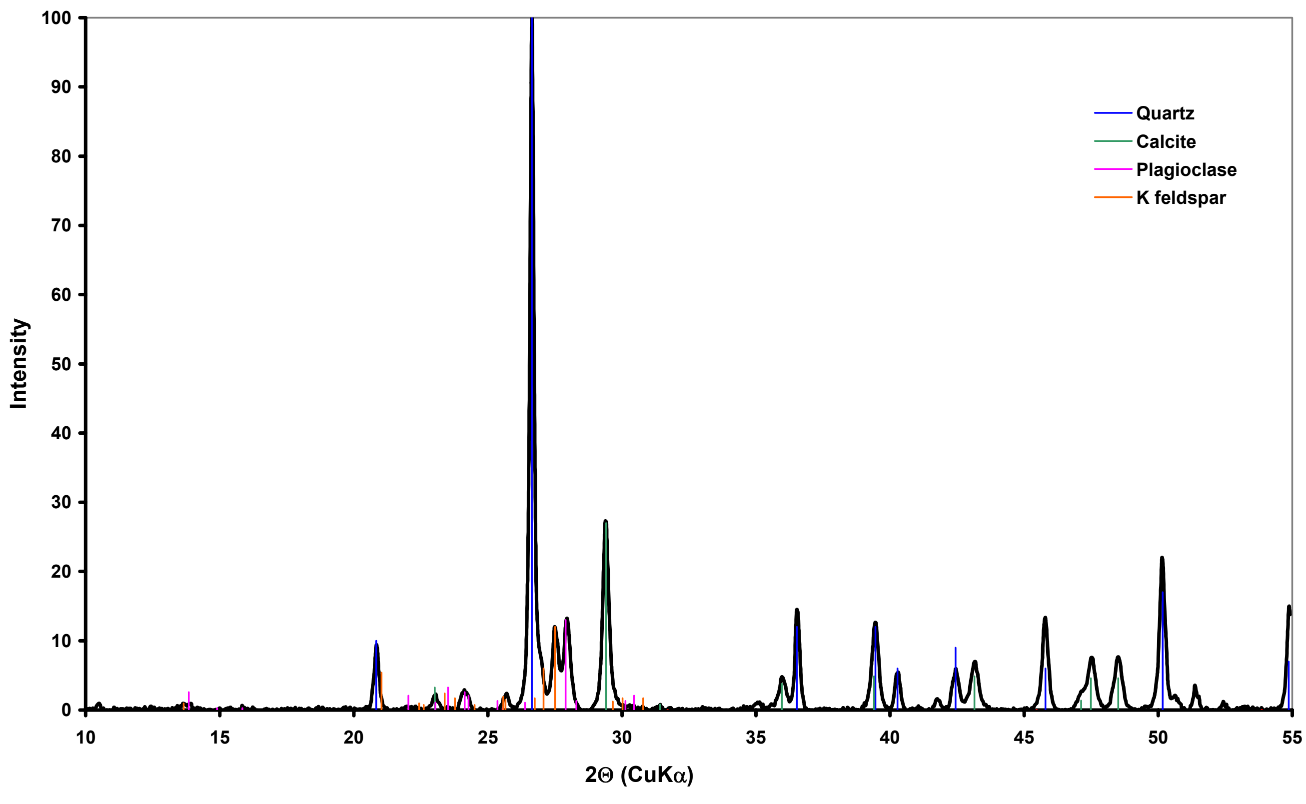

**X-ray diffractogram of wall plaster, Al Zubarah city, area of consolidation (figure 11)**



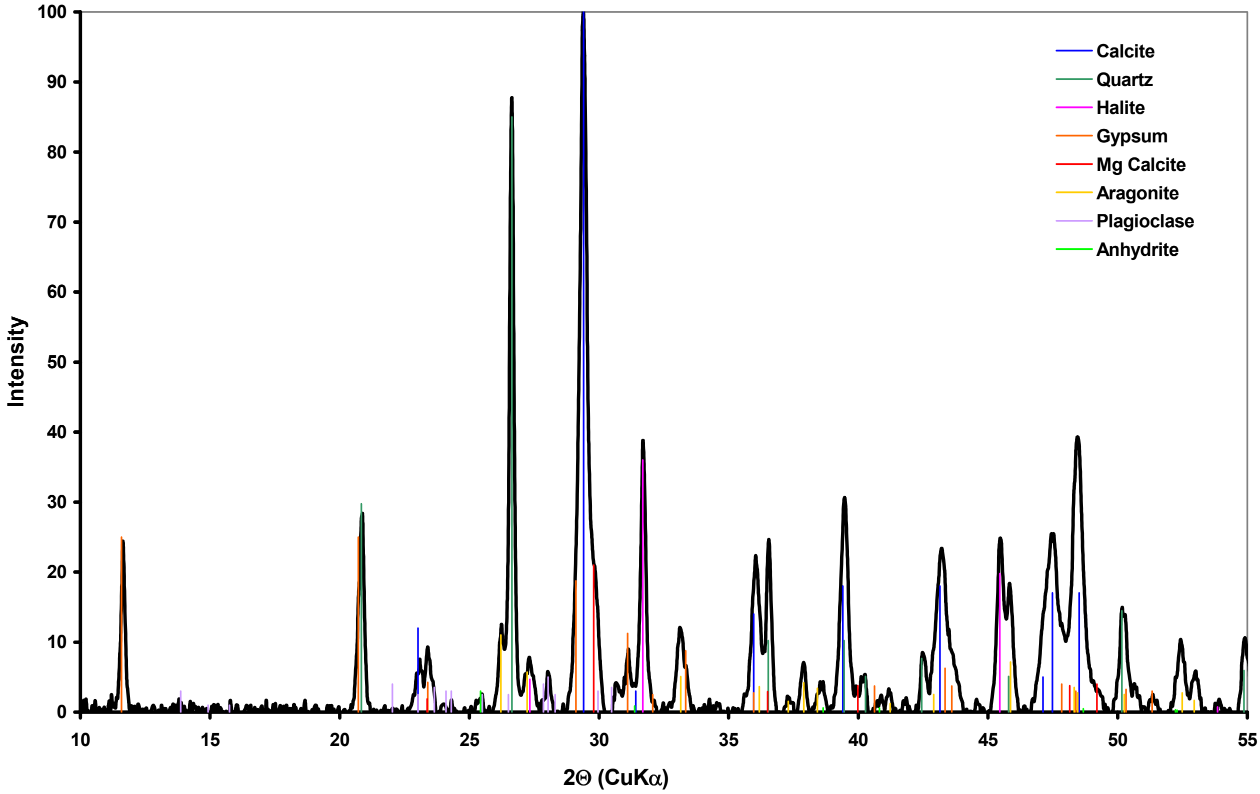

**X-ray diffractogram of wall render, Al Zubarah fort (figure 13)**



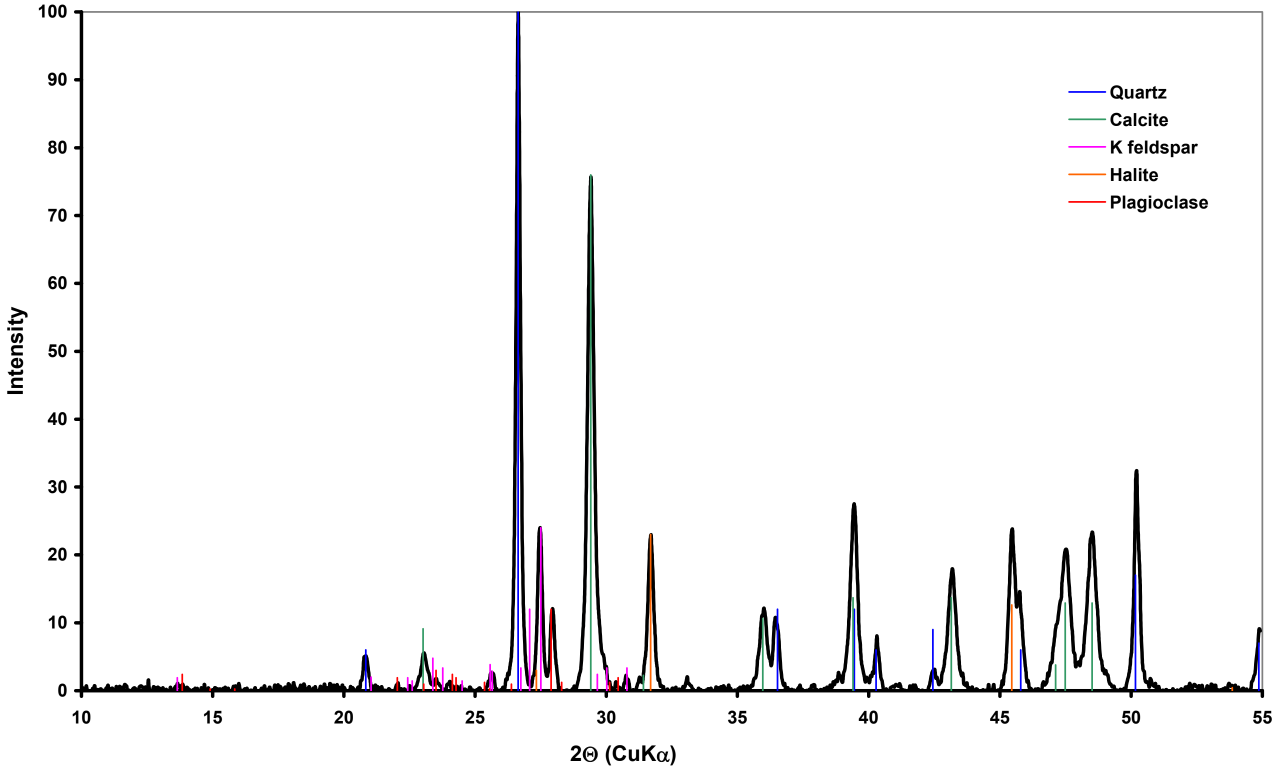

**X-ray diffractogram of wall render, Al Rikiyat fort (figure 13)**



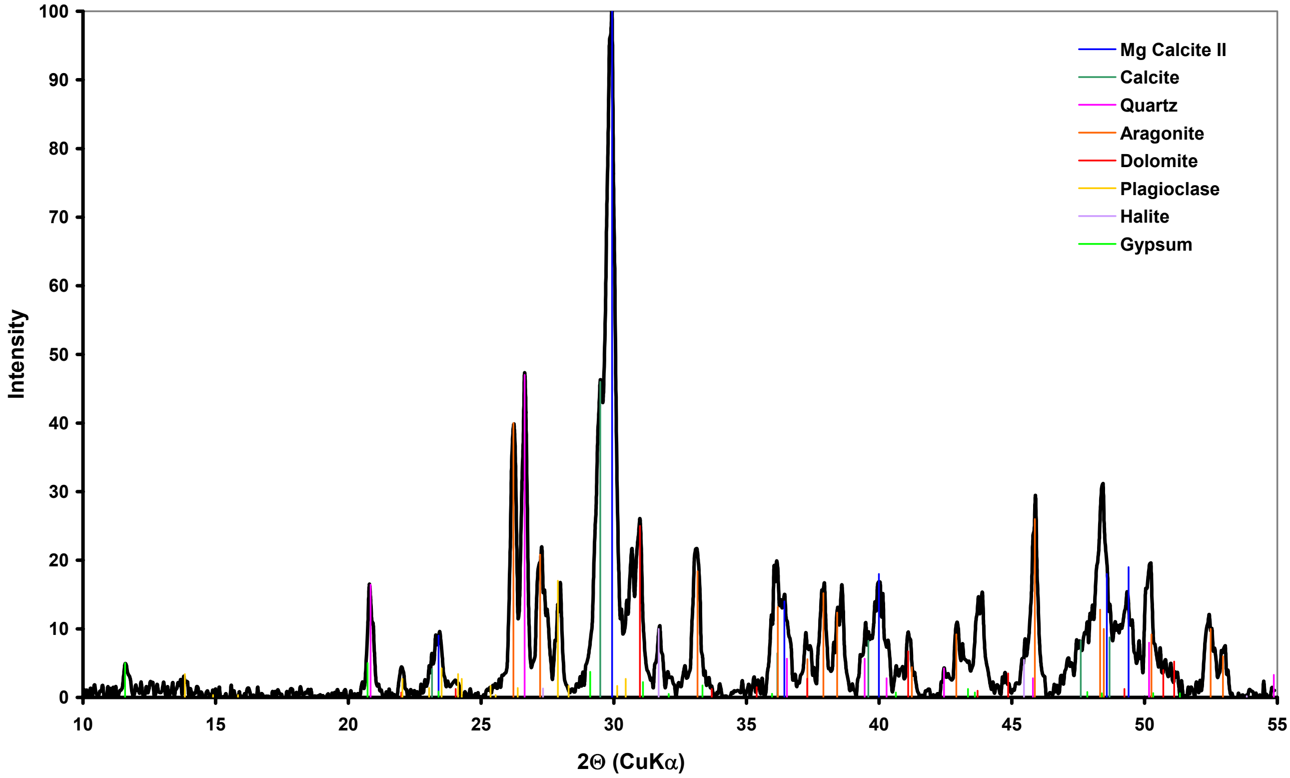

**X-ray diffractogram of hydraulic lime wall mortar, test area II, Eastern part of tower structure (figure 15 )**



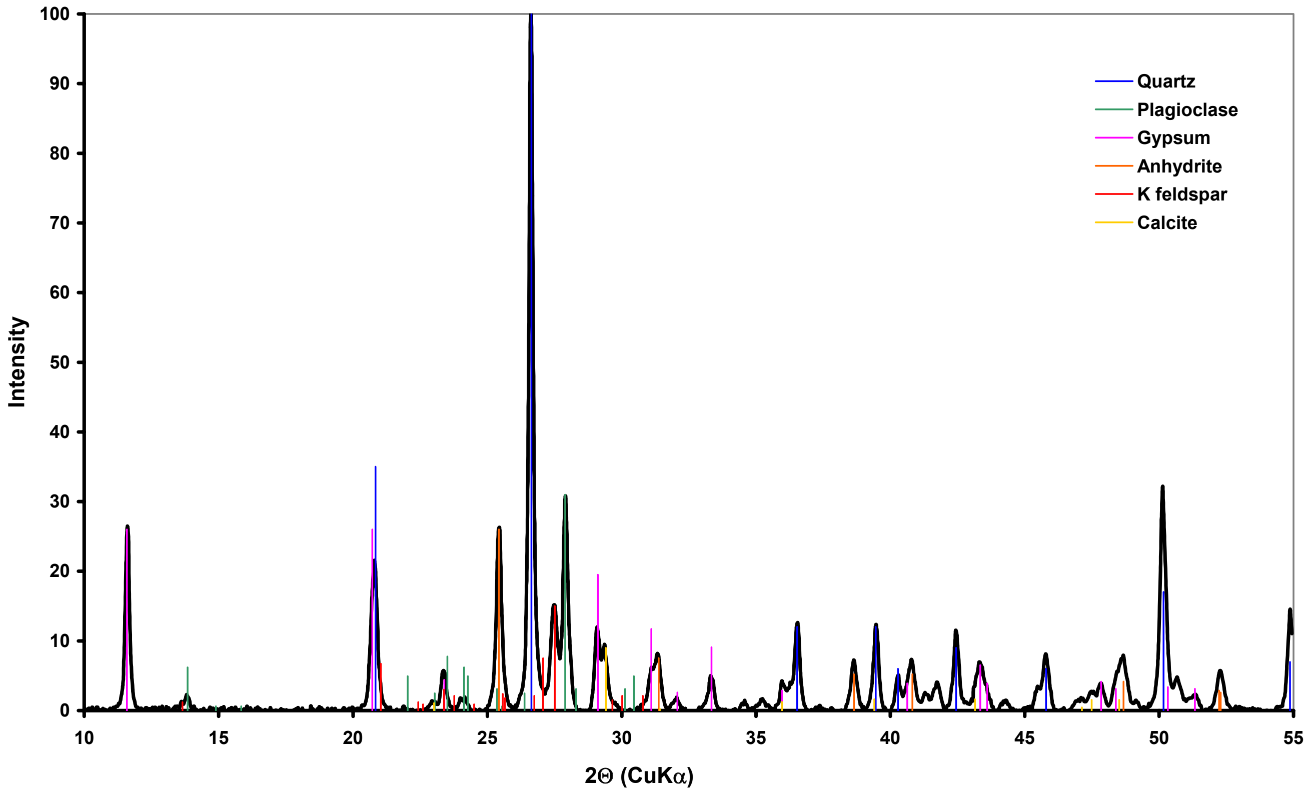

**X-ray diffractogram of hydraulich lime mortar from joint, test area XI, Eastern part of tower structure (figure 15 )**



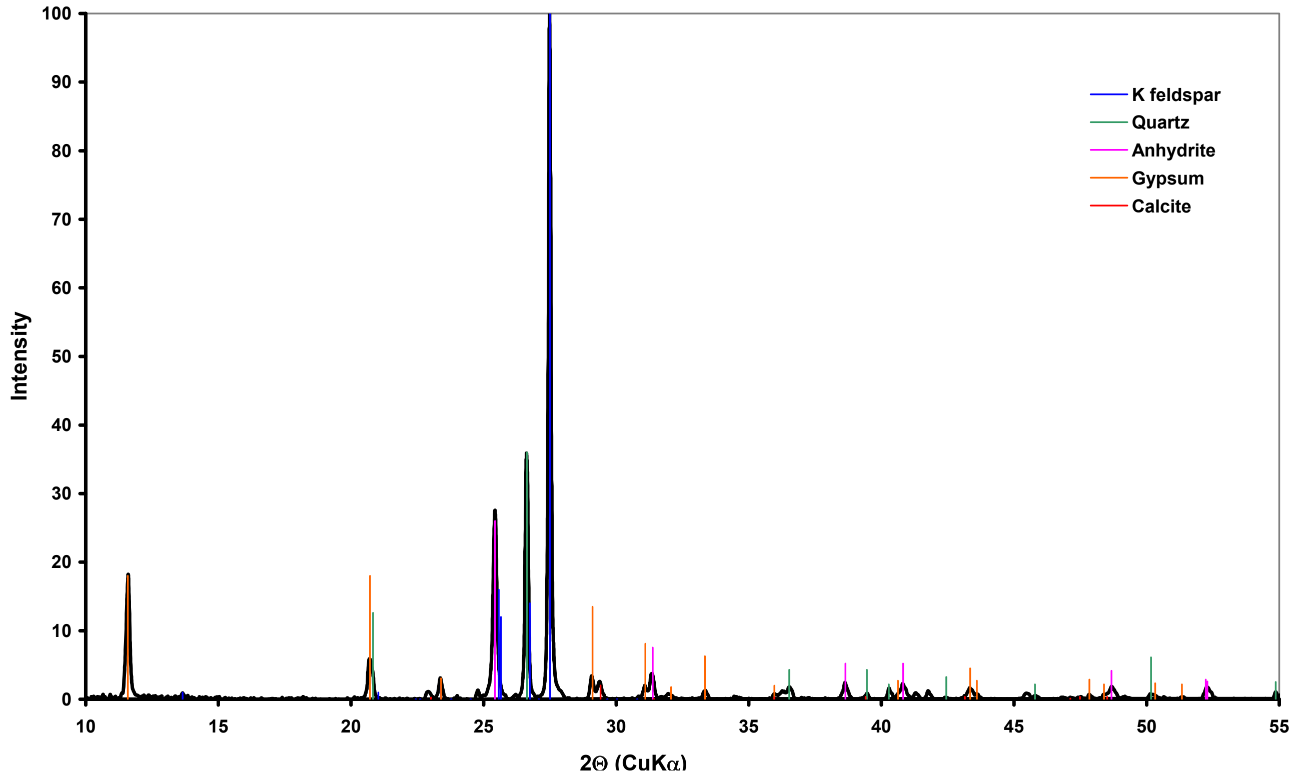

**X-ray diffractogram of hydraulic lime mortar as render , test area XII, Southern part of tower structure**



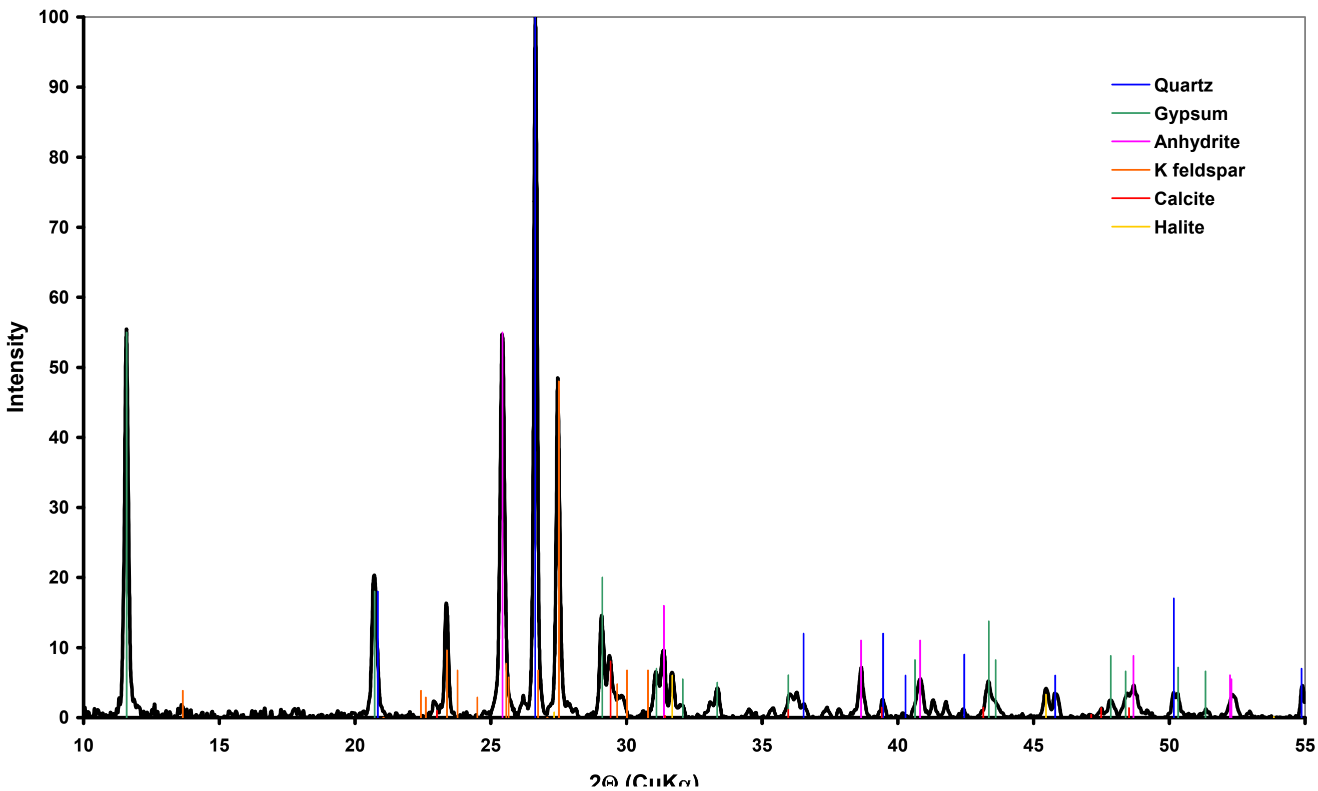

**X-ray diffractogram of hydraulic lime mortar as render , test area XIII, Western part of tower structure**



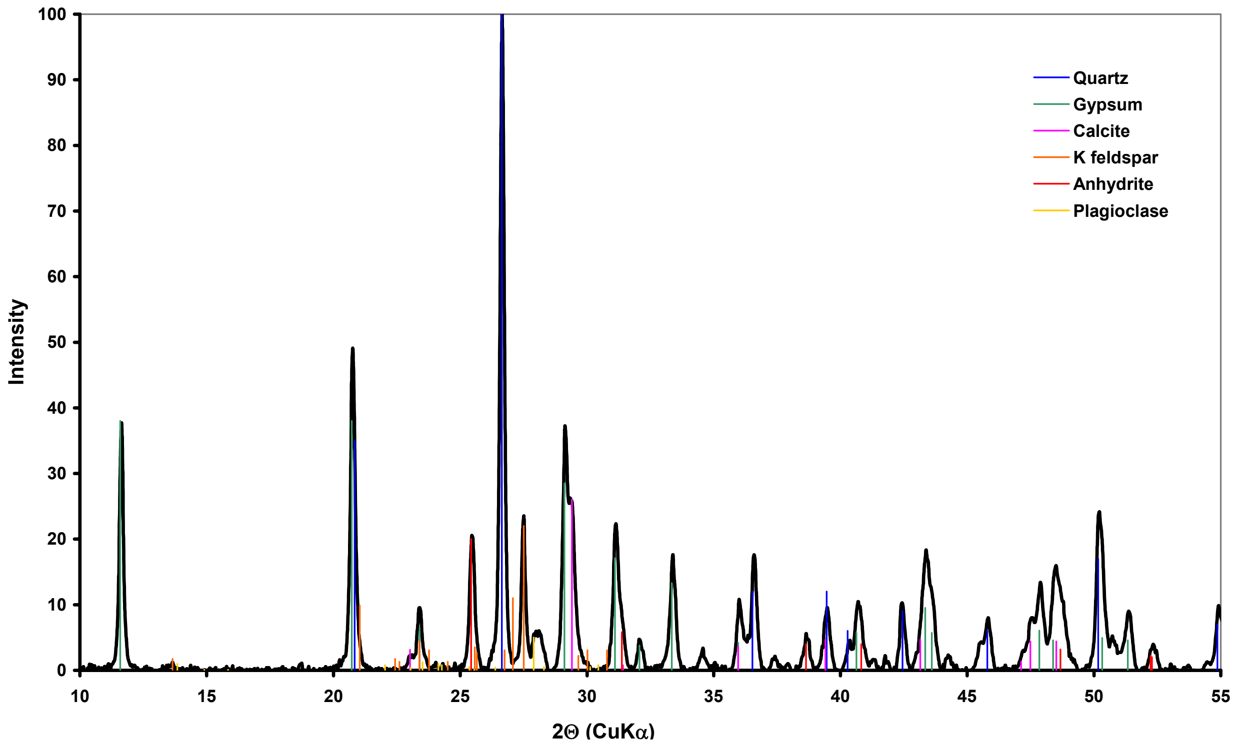

**X-ray diffractogram of anhydrite mortar from joint , sample IV, area of consolidation**



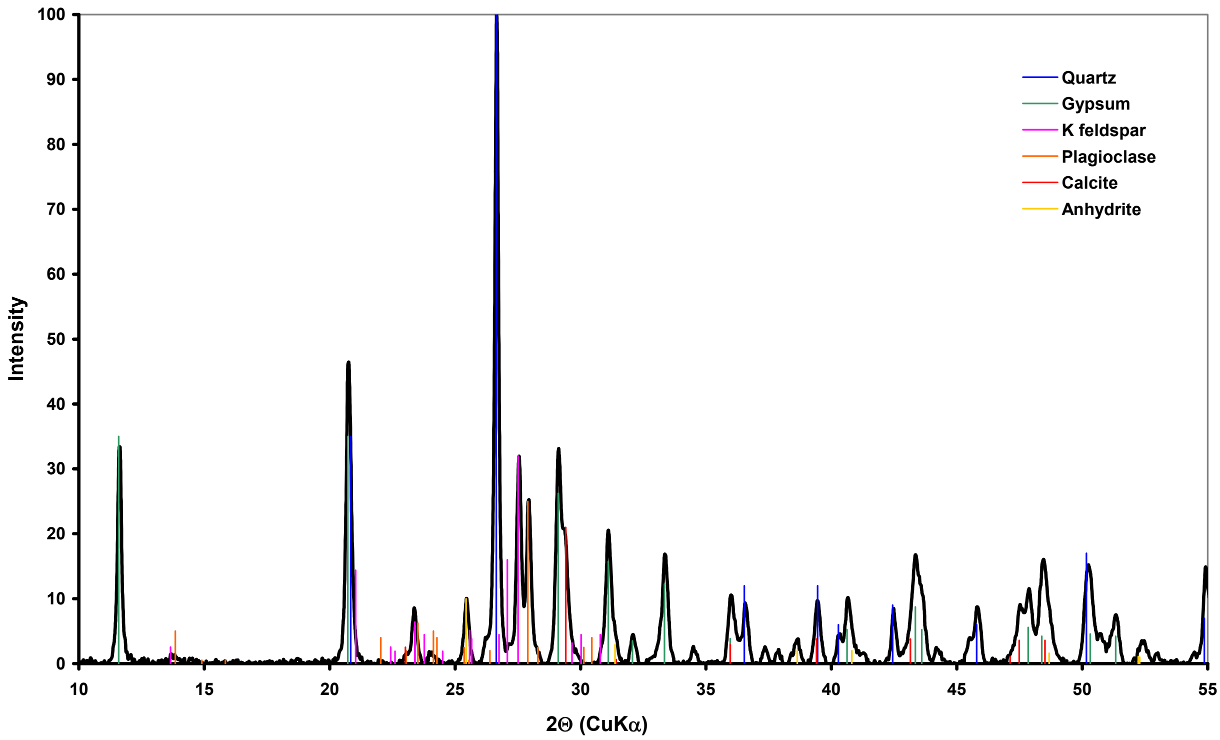

**X-ray diffractogram of anhydrite mortar from joint , sample IX, area of consolidation**



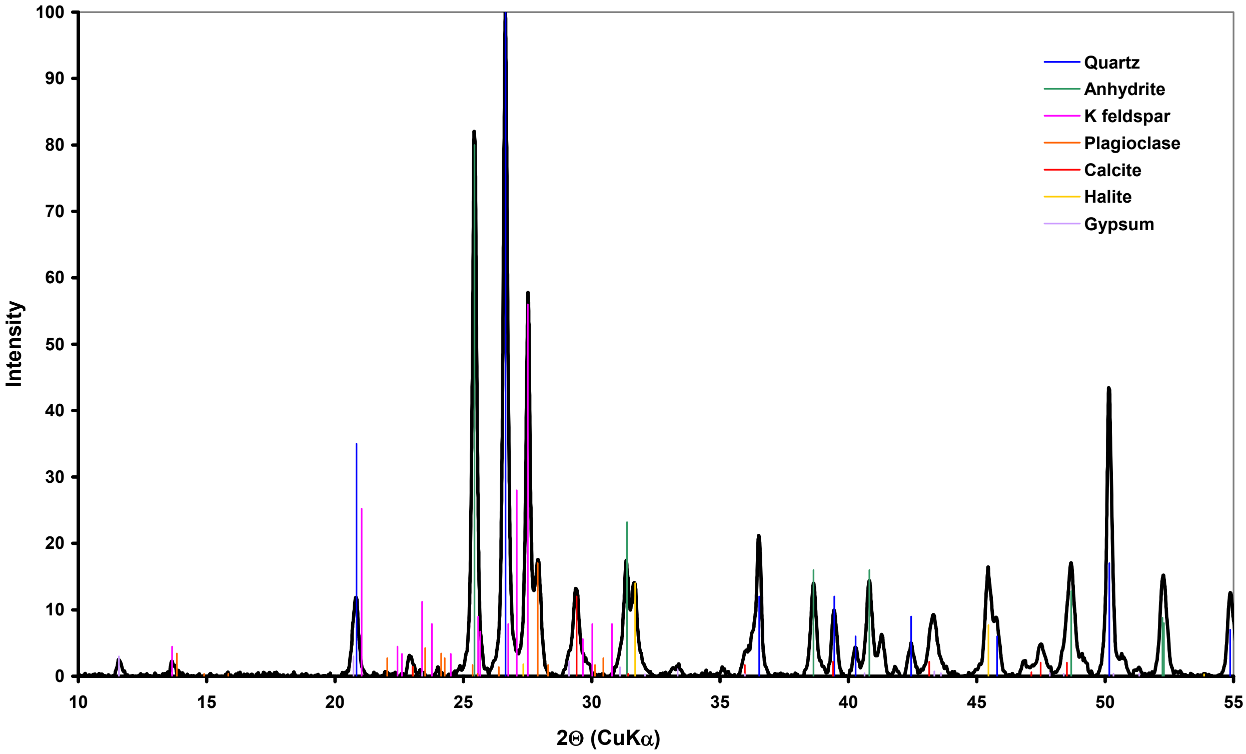

**X-ray diffractogram of anhydrite mortar from joint , sample X, area of consolidation**



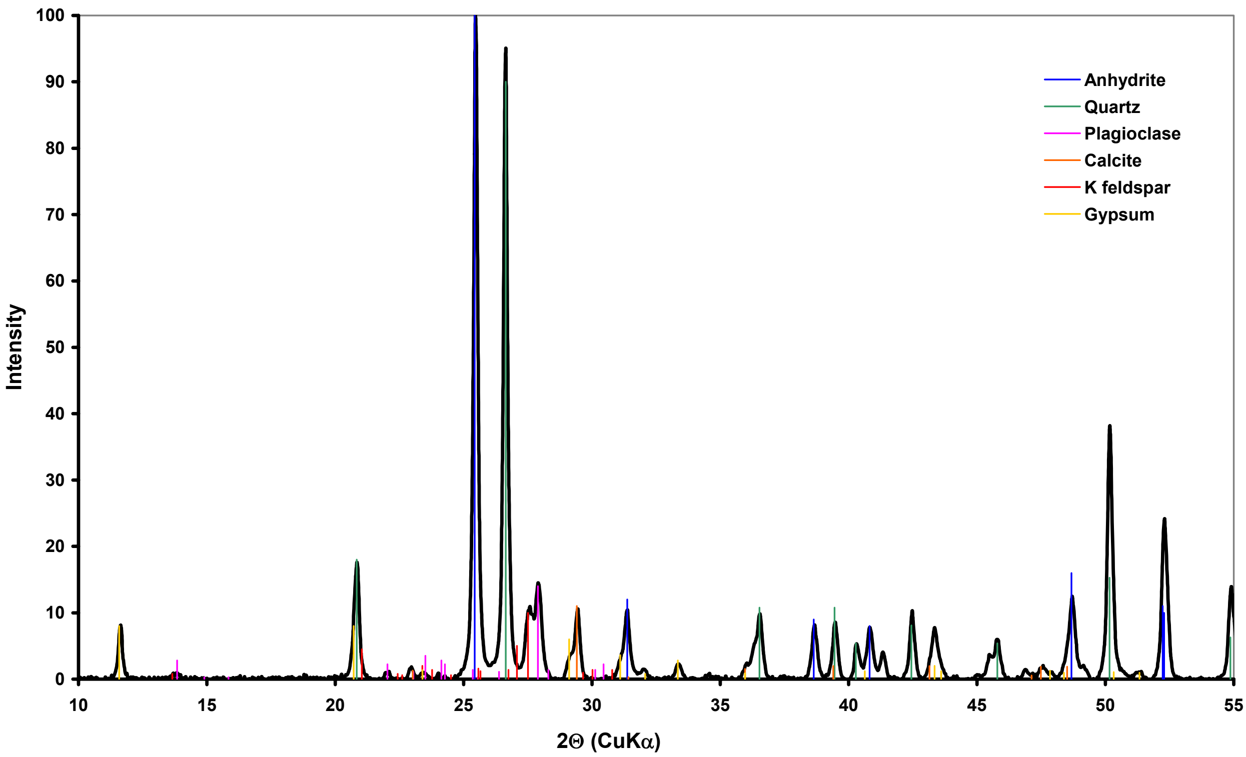

X-ray diffractogram of anhydrite plaster sample F



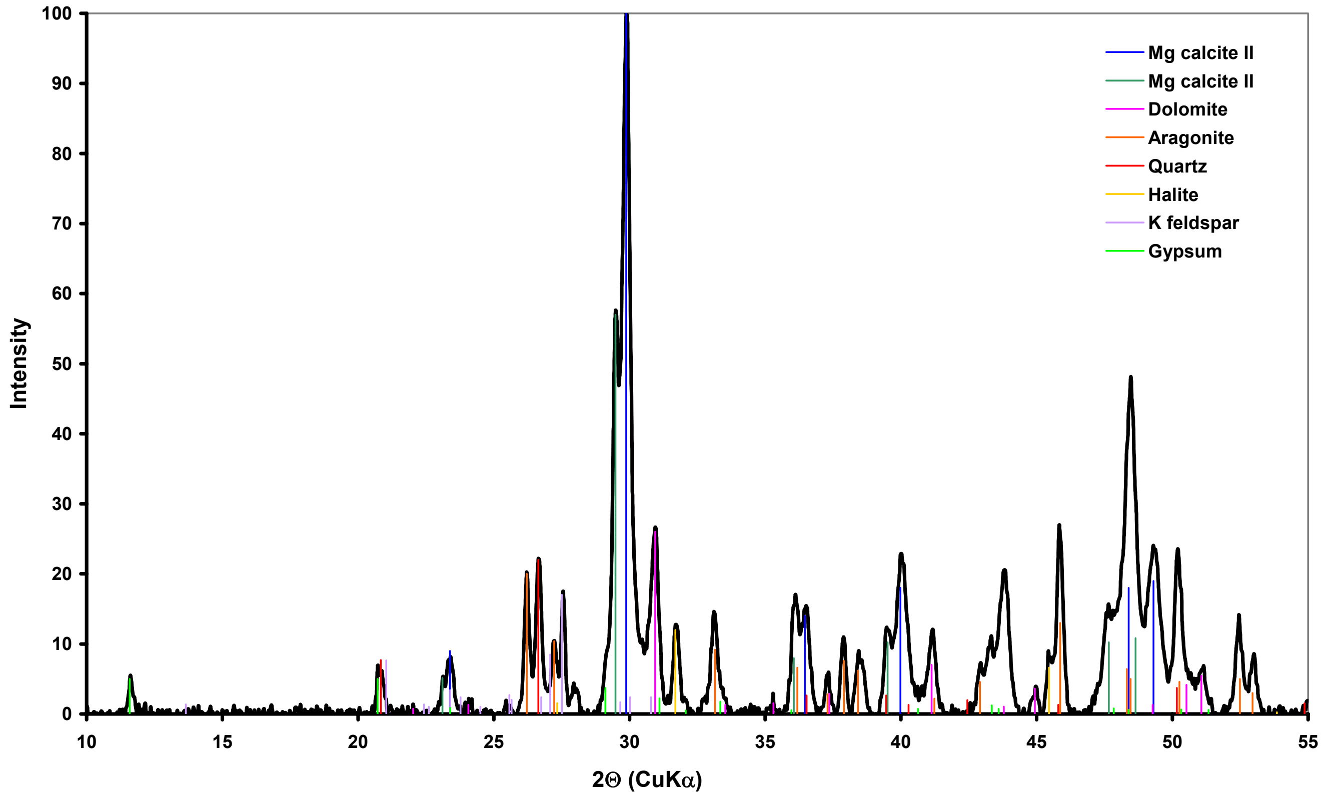

X-ray diffractogram of anhydrite plaster sample G




**X-ray diffractogram of anhydrite plaster sample HAP**




**X-ray diffractogram of anhydrite plaster sample AB**




**X-ray diffractogram of beachrock after treatment with “nano lime” solution (colloidal solution of portlandite in ethanol), testfield 2b, area of consolidation, Al Zubarah city**

APPENDIX 4

# Analyses and Tests on BUILDING MATERIALS

## AT AL ZUBARAH / QATAR

Report by Robert Sobott
covering the period of 1.10.2011 to 23.03.2012

# Report II  about the work done from 1.10.2011 –  23.03.2012

**by  R. Sobott, LfBD NMB, IMKM University of Leipzig**

**1. Chemical analyses of building materials**

**2. Investigation of particular mortars**

**3. Production and application of anhydrite plaster in Al Zubarah**

**4. Consolidation test on gypsum plaster with Xilan**

**5. Delivery and installation of analytical equipment for on-site laboratory**

**6. Identification of rocks and objects made of stone  in the find magazine**

**7. Cooperation with Materials Science Unit of Qatar University**

**8. Outlook**

**8.1 Documentation of changes in the state of walls as a function of time**
**8.2 Consolidation of gypsum wall plaster**
**8.3 Visit to comparable excavation projects in the Gulf States**

**9. Stays in Qatar (Doha, Al Zubarah)**

**16.10. – 20.10.2011  ICOMOS**
**29.11. – 04.12.2011  Workshop**
**14.01. – 19.01.2012  Working session of strategy group**
**26.02. – 03.03.2101  Working session of strategy group**

**(All figures have been  copied to the enclosed CD so that they can be viewed at higher magnification on the computer screen).**

## 1. Chemical analyses of building materials

The ubiquity of salts in the environment of Al Zubarah is a challenge to the longevity of every building material. Foremost it is sodium chloride that can be found as white efflorescence on rocks or as a disseminated component in the beach sand or soil of the sabkha zone. Sodium chloride (rock salt) and other salts with a good solubility in water are damaging to the stability of building materials by various physical and chemical reactions. For instance, in the course of crystallization or hydration pressure will be exerted on the walls of pores inside the building material by the the growing or transforming salt crystals. If this pressure exceeds the tensile strength of the mortar it will crack. Repeated or cyclical crystallization and dissolution will eventually destroy the fabric and lead to a collapse of the structure. Also chemical reactions which transform binding components such as portlandite into water-soluble compounds contribute to the destruction of the mortar. An example for this kind of mortar deterioration is the reaction of portlandite with halite in the presence of carbon dioxide to form thermonatrite according to the chemical reaction:

$$Ca(OH)_2 + 2\ NaCl + CO_2 \rightarrow Na_2CO_3{*}H_2O + CaCl_2 \qquad \Delta G = 3{,}31\ kcal/mol$$

Although this reaction is slightly endothermic at standard conditions efflorescences of thermonatrite on render made with natural hydraulic lime is regarded as evidence that the formation of thermonatrite takes place in this or a very similar way (**figure 1**). Thus by physical and chemical processes related to the presence of salt solid render and mortar is more or less quickly transformed into a poor heap of debris at the foot of a wall.

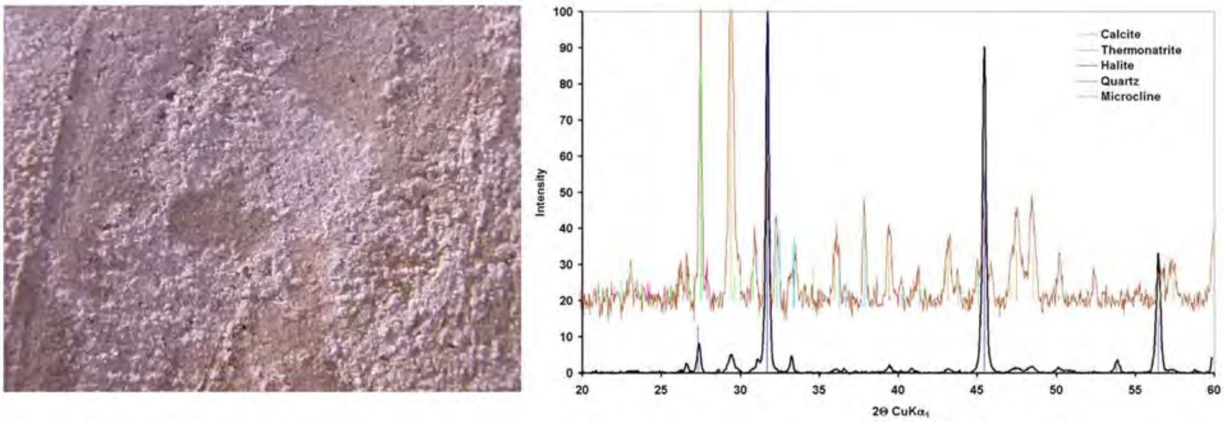



**Figure 1: Salt efflorescences on fresh NHL render. Right: X-ray diffraction diagrammes of efflorescences**

In order to get an idea in what quantities salts are present in the building materials of Al Zubarah, a number of analyses of respective materials were made. The samples were prepared by elution of the salts with distilled water. 10g of the dried sample were put in a glas container with 500 ml distilled water and shaken for 24 hours. After separation of the insoluble residue the clear solution was used for the determination of cations by ICP-OES and the anions by ion chromatography. Due to the limited solubility of gypsum in water (~ 2g/l) the amount of sulfate analysed depends on the ratio of sample mass to water volume (usually 1:50) and the amount of sulfate present in the sample.

The building materials include old mortar/render samples (6, 7, 8, 12, 13, 14) as well as a sample of "soil" (21) used for mixing mortar and the resulting mortar (15). Also samples of originally salt-free quartz sand (9, 10, 11) which were used for covering a plaster floor at EP 04 were analysed after several month of exposure to check how long it takes for salts to accumulate.

The results in **table 1** show that chloride and sulfate are omnipresent while nitrate practically plays no role.

**Table 1: Contents of water-soluble salts in different building materials**

| Sample | Sulfate [Mass%] | Nitrate [Mass%] | Chloride [Mass%] | Calcium [Mass%] | Magnesium [Mass%] | Sodium [Mass%] | Potassium [Mass%] | Total [Mass%] |
|---|---|---|---|---|---|---|---|---|
| **6** | 1,57 | 0,03 | **12,25** | 0,70 | 0,13 | 7,5 | 0,27 | 22,45 |
| **7** | 0,17 | 0,04 | 1,45 | 0,11 | 0,03 | 0,90 | 0,08 | 2,77 |
| **8** | 1,73 | 0,19 | 2,40 | 1,10 | 0,20 | 1,250 | 0,16 | 7,02 |
| **13** | 0,67 | 0,02 | 5,75 | 0,35 | 0,25 | 3,10 | 0,21 | 10,35 |
| **14** | 2,71 | 0,13 | 1,91 | 1,35 | 0,16 | 1,05 | 0,12 | 7,41 |
| **9** | 0,23 | 0,01 | 0,55 | 0,13 | 0,03 | 0,38 | 0,026 | 1,34 |
| **10** | 0,28 | 0,01 | 0,41 | 0,15 | 0,02 | 0,28 | 0,02 | 1,17 |
| **11** | 0,19 | 0,01 | 0,37 | 0,11 | 0,02 | 0,23 | 0,02 | 0,94 |
| **12** | 7,10 | < 0,001 | 1,01 | 3,20 | 0,06 | 0,70 | 0,09 | 12,16 |
| **15** | 0,82 | 0,27 | 3,19 | 3,05 | 0,000 | 1,85 | 0,17 | 9,34 |
| **21** | 2,82 | 0,00 | **19,70** | 1,05 | 0,16 | 9,00 | 0,10 | 32,82 |

| Sample | Description | Sampling locality |
|---|---|---|
| **6** | wall and joint mortar | ZU QMA 03 R 0002 W 0001 |
| **7** | wall and joint mortar | ZU QMA 03 R 0006 W 0013 |
| **8** | wall and Joint mortar | ZU QMA 03 R 0072 W 0153 |
| **13** | wall and joint mortar | ZU QMA 03 R? W 131/132 |
| **14** | wall and Joint mortar | ZU QMA 03 R 0072 W 0153 |
| **9** | Sand 1 | EP 04 |
| **10** | Sand 2 | EP 04 |
| **11** | Sand 3 | EP 04 |
| **12** | Plaster from south tower | EP 04 |
| **15** | soil mortar P 1.32 | - |
| **21** | „soil“ | close to city wall and tower 8 |

From the results in table 1 it is evident that the wall and joint mortars (samples 6, 7, 8, 9, and 10) accumulate appreciable amounts of sodium chloride by and by. The accumulated salts will eventually deteriorate the strength of the mortar by the processes mentioned above. Therefore it is of utmost importance to prepare the mortars with salt-free materials. That the accumulation of salt in salt-free mortars takes some time is indicated by the data for the samples 9, 10, and 11. These are samples from the quartz sand which was used to cover the plaster floor of a room in the palace compound at EP 04. In the course of 6 - 8 month average amounts of 0,44 mass% chloride and 0,23 mass% sulfate have accumulated in the sand. Given a much lower permeability of the mortar than of a loose sand layer it can be estimated that the accumulation of considerable amounts of salt in a mortar will take at least 4 – 5 years. On the other hand, if salt-containing sand (sample 21 in table 1) is used for the preparation of mortar its salt content (sample 15 in table 1) will be right from the start as high as it will be after several years of accumulation. Therefore the pleading for the use of salt-free building materials is not based on the idea that the mortar will stay salt-free but rather on the idea of having it almost salt-free for at least one year during which it can develop undisturbedly the strength which it will need to sustain the salt attack for at least 10 years.

Salt attack will not take place equally at the exposed walls. It is to be expected most effectively at the foot zone due to the capillary rise of brines from the soil. With respect to weathering also the physical effect of wind abrasion plays an important role. Therefore the geographical direction of the exposure of a wall will have an effect on the longevity of mortars and renders. Render on luv walls is supposed to have a higher physical weathering rate due to the abrasive wear by sand particles than on lee walls.

The meticulous documentation and observation of test walls with different mortars in terms of weathering and deterioration will lead to an optimization of building materials and techniques.

## 2. Investigation of particular mortars

Special attention was paid to two mortar samples in connection with repair work at Al Zubarah fort and with the plastering of the walls at EP 04 and and the city wall between the towers 8 and 9.

### 2.1 Mortar for the roof of Al Zubarah fort

The test slabs made by Kenneth were inspected on the 16th of January 2012, together with Owain Evans and Moritz Kinzel. The test outcome was very mixed and at least three different results could be observed **(figure 2**)


**Figure 2: Lime concrete test slab (above) with different states of aggregate/matrix fabric**

A quick on-site evaluation of the results led to the following statements:

1. A better compaction of the lime concrete is needed in order to avoid the formation of large voids.

2. To minimize the amount of free pore space it is necessary to blend the dolomite aggregate (maximum grainsize diametre: 8 mm) with a sand with a higher proportion of fine grains.

Samples of the old OPC concrete and the new hardened lime concrete (**figure 3**) were taken for the determination of the bulk density, compressive strength, and Young's modulus. The results of the tests are summarized in **table 2**..

**Table 2: Physical properties of aggregate and hardened lime concrete**

| **Material** | **bulk density** [g/cm³] | **compressive strength** [N/mm²] | **Young's modulus** [kN/mm²] |
|---|---|---|---|
| quartz sand | 1,72 | - | - |
| dolomite aggregate | 1,56 | - | - |
| lime concrete | 1,76 | 3,3 / 2,8 | 4,7 |
| OPC concrete | | > 10 | |

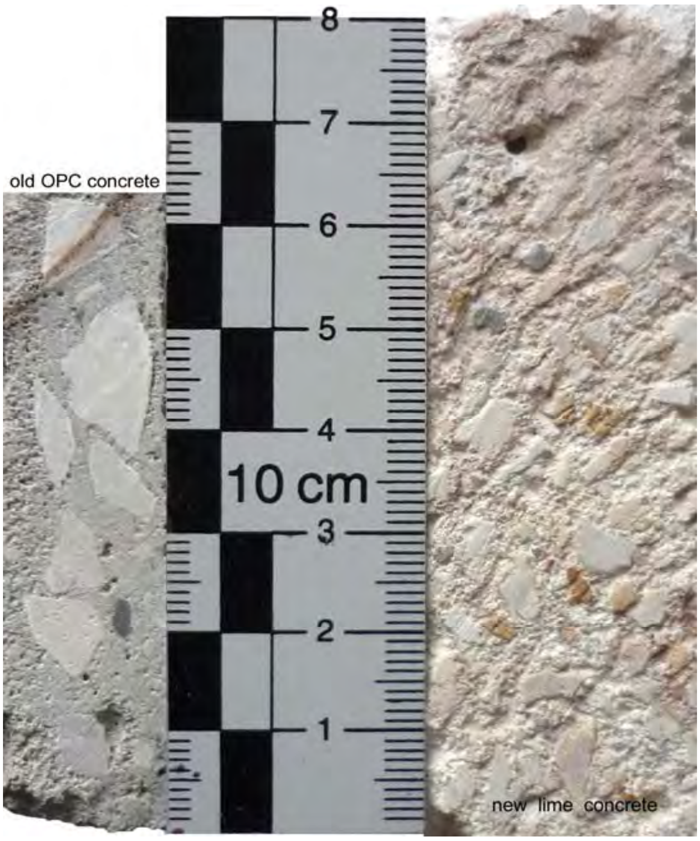



**Figure 3: Old OPC** (left side) **and new lime concrete**

Samples of the dolomite aggregate and quartz sand were taken for the determination of the bulk density and the grain size distribution (gsd) (**figure 4**).

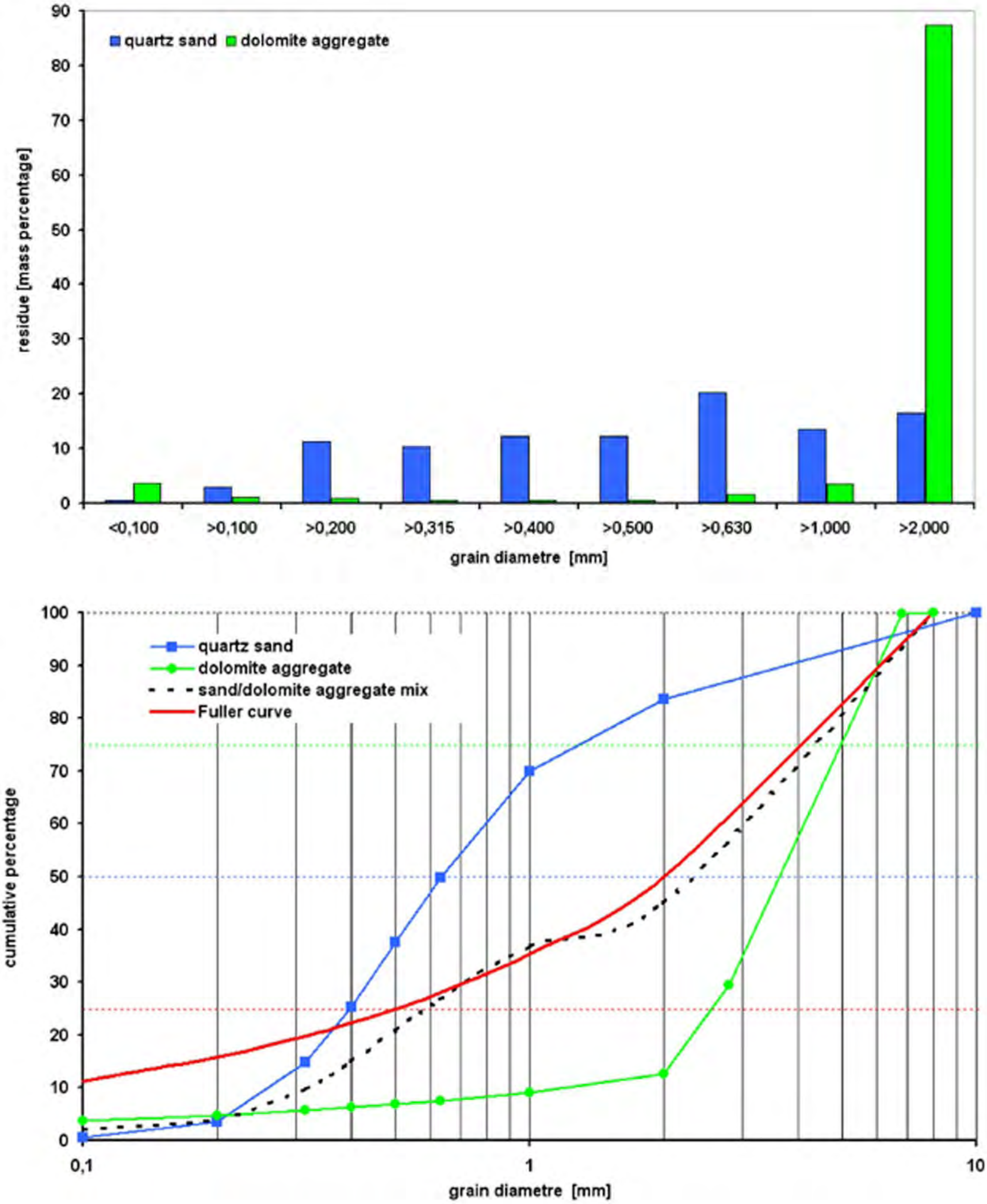



**Figure 4: Histogram and grain size distribution of quartz sand, dolomite aggregate and a 3 to 4 mixture of these**

**Conclusions**

On-site observations and test results lead to the following recommendations:

1. As the grain size distribution of the dolomite is rather uniform the packing of the dolomite fragments will always result in a highly porous structure as shown in picture 2 of figure 1. In order to minimize the open pore space the dolomite aggregate should be mixed with quartz sand which exhibits a much more even grain size distribution. The best result with respect to the Fuller curve describing the ideal grain size distribution will be achieved by mixing 4 volume parts of dolomite aggregate wit 3 volume parts of quartz sand. Such a mixture will yield a darker, more yellowish-grey colour of the lime concrete. **Maybe the resulting colour is more pleasing than the offensive white colour of the present lime concrete.**

2. The compressive strength of the tested samples falls behind the expected value of 7 – 8 N/mm². Although the tested samples (4 x 4 x 4 cm³ cubes) had not developed the final strength as a result of complete carbonatizastion of portlandite it is not to be expected that it will eventually exceed 5 N/mm² very much if at all. This may still be acceptable. However, a further reduction of binder to aggregate ratio from 1:3 to 1:3,5 is not recommendable. Depending on the outcome of the compressive strength tests on the samples still kept at the fort it might even be advisable to increase the WOPC content in the binder mixture from 1:3 to 1.5 : 2,5. **[As far as I am informed there ist no NHL in Qatar available. Was the imported Otterbeiner Hydradur NHL 5 used as binding component or was it the white hydrated lime ? This point needs clarification. The bright white colour and the comparable low strength of the lime concrete let me think that hydrated lime was used instead of NHL.]**

3. According to information given by Kenneth the best result with respect to the fabric of the lime concrete (picture 3 in figure 1) was obtained with a mixture containing 5 volume parts quartz sand, 9 volume parts dolomite aggregate, 1 volume part OPC, 3 volume parts hydrated lime (?) and 2.2 volume parts water. **Therefore I recommend that the water to binder ratio should be fixed at 0,55**. If the mixture is too dry (water to binder ratio = 0,45) it is hardly workable and the aggregate particles will not settle properly.

4. Compaction of the lime concrete is an absolute must. Kenneth knows about it and has proposed to build a suitable tool for manual compaction.

5. The maximum load put on to the lime concrete slab in a sort of on-site bending tensile strength test did not reach a critical value. Evaluating the data (**table 3**) and fotografs (**figure 5**) supplied by Moritz the maximum bending force did not exceed 0,013 N/mm² which is far beyond the value of $ß_{BZ}$ ~ 0,16*2,8 N/mm² = 0,45 N/mm² where fracture may occur. Therefore the question arises what was the intention of the test ?

**Table 3: Data of on-site bending tensile strength test**

| **mass** [kg] | **no. of sacks** | **load** [N] | **area** [mm²] | **force** [N/mm²] | **flexure** [mm] | |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | | | 0 | |
| 100 | 2 | 981 | | | 0 | |
| 200 | 4 | 1962 | | | 0 | |
| 300 | 6 | 2943 | | | 0 | |
| **400** | **8** | **3924** | **480000** | **0,008** | **0** | **→ see figure 5** |
| 500 | 10 | 4905 | | | 0 | |
| 600 | 12 | 5886 | | | 5 | |
| 650 | 13 | 6377 | | | 5 | |


**Figure 5: On-site bending tensile strength test**

## Epilogue

As set out in point 2 of the conclusions the test slab was made with hydrated lime instead of natural hydraulic lime. The actual execution of the work was done with Otterbeiner NHL 5 and a change in the composition of the aggregate was made as set out in point 3 of the conclusions.

## 2.2 Characterization of the white ordinary Portland cement (WOPC)

Mortar for the stabilisation and reconstruction work of the walls in Al Zubarah city should fulfil the following requirements:

- rapid development of initial strength
- resistance to the chemical attack by sulfates and chlorides
- colour that fits the stonework
- easy availability in Qatar

The natural hydraulic lime mortar Otterbeiner Hydradur NHL 5 fulfils the first three requirements but is unhappily not available in Qatar. The last point being a crucial issue made it necassary to look for an adequate substitute. The general idea was to create an artificial “natural hydraulich lime” by mixing appropriate amounts of hydraulic lime and ordinary Portland cement OPC which are available in Qatar. The search yielded three products: hydrated lime (HL), Portland cement with a high resistance to sulphate attack (PC-SR, with a C3A content lower than 3 wt.%), and white ordinary Portland cement (WOPC). Laboratory experiments carried out in Naumburg with HL and Schwenk PC CEM 42.5R SR showed that an artificial “natural hydraulic lime mortar” with almost identical properties with respect to strength and resistance to sulphate attack can be mixed from HL and PC-SR, the volume ratio varying between 3:1 and 4:1 (HL:PC-SR) (**figure 6**).

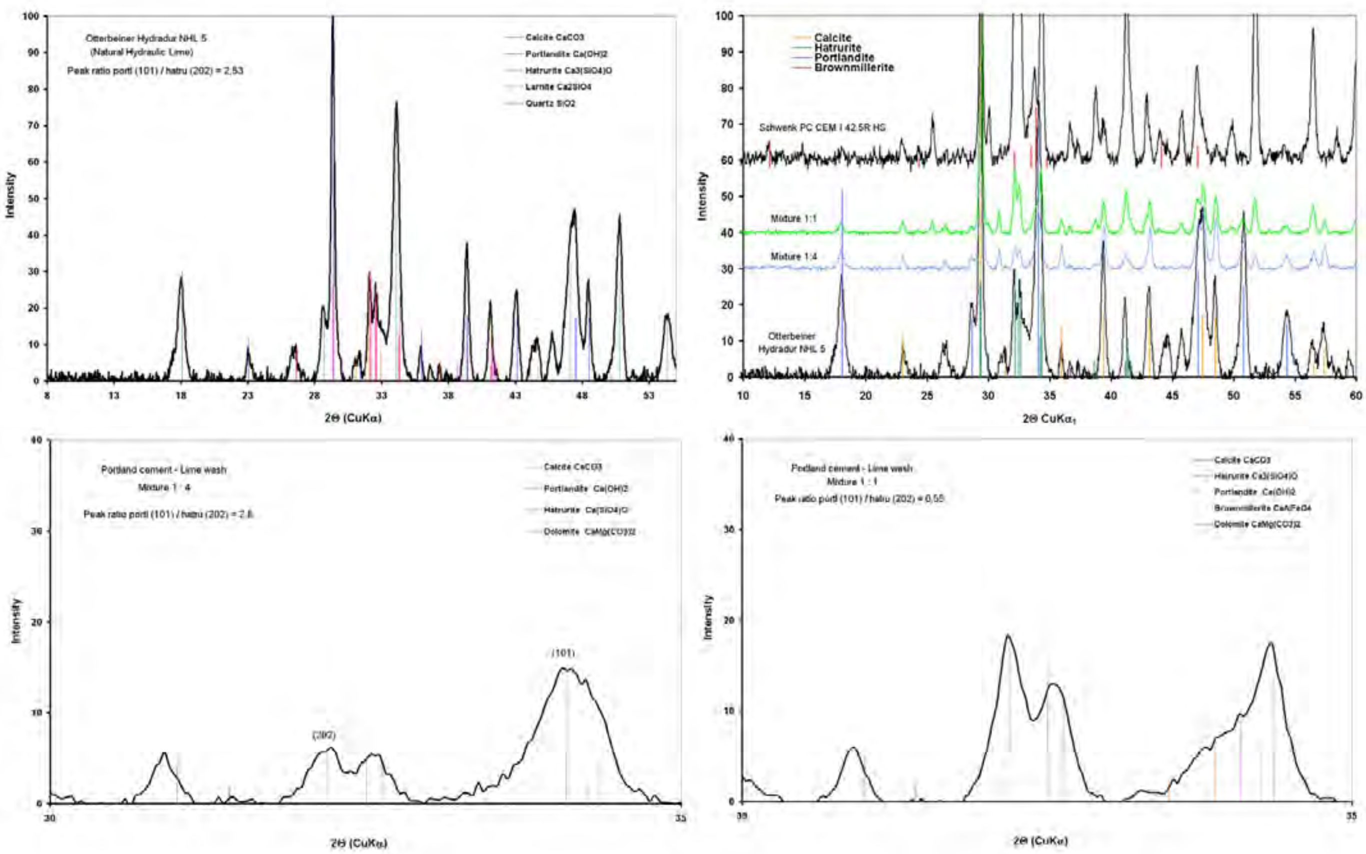



**Figure 6: X-ray diffractometry of mortar mixtures with HL and PC-SR as a substitute for NHL**

However, tests carried out in Al Zubarah with PC-SR showed that the colour of the resulting mortar was intolerable dark. Therefore PC-SR was replaced by WOPC with very good results as far as the mortar colour was concerned.

The binding materials HL and WOPC were analysed by X-ray diffractometry and X-ray fluorescence spectroscopy in order to establish the chemical and phase composition. It turned out that the HL consists entirely of portlandite $Ca(OH)_2$ and the WOPC of the cement clinker minerals hatrurite, larnite, and tricalciumaluminate (C3A) portlandite and calcite (**figure 7**).

Tricalciumaluminate can be a dangerous component in the presence of sulphate and water because it can react with these two compounds to form ettringite and/or thaumasite which will eventually destroy the mortar. Therefore it was necessary to determine the absolute content of C3A in the WOPC and to test the behaviour of a WOPC-containing mortar in contact with sulphate (gypsum) and water. The test was carried out with the so-called soil mortar P 1.32 with sulphate content of just 0,82 wt.%.

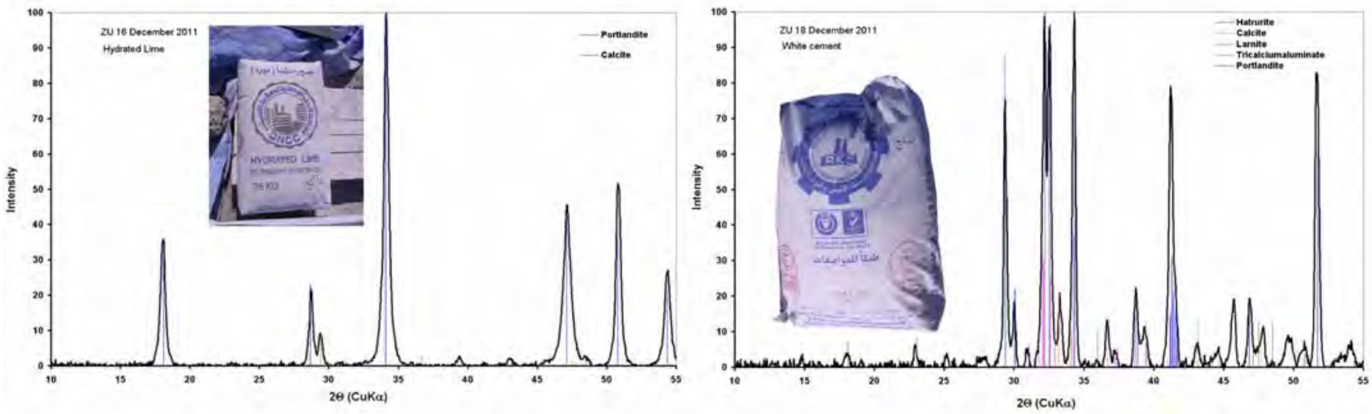



**Figure 7: X-ray diffractograms of HL and WOPC**

The chemical analysis showed that the $C_3A$ content is as high as 11,6 mass % **(table 4**) which can **lead to problems if WOPC is used in sulphate-rich environments due to the formation of ettringite and/or thaumasite**.

**Table 4: Chemical and phase composition of WOPC**

| Chemical composition | | Phase composition | |
|---|---|---|---|
| $Na_2O$ | 0,03 | $C_3S$ | 48,5 • |
| $K_2O$ | 0,08 | $C_2S$ | 29,2 • |
| MgO | 1,18 | $C_3A$ | 11,6 • |
| CaO | 66,59 | $C_2(A,F)$ | 0,5 |
| $Al_2O_3$ | 4,34 | Calcite | 4,90 • |
| $Fe_2O_3$ | 0,17 | Portlandite | 2,21 • |
| $Cr_2O_3$ | 0,003 | Anhydrite | 3,13 |
| $SiO_2$ | 22,21 | **Sum** | 100,04 |
| $TiO_2$ | 0,21 | | |
| $SO_3$ | 2,05 | | |
| **LOI** ($H_2O$, $CO_2$) | 3,00 | | |
| **Sum** | **99,86** | | |

• Phases identified by X-ray diffraction

These two phases are the reaction products of sulphate (gypsum) with aluminate ($C_3A$) and/or silicate (CSH) in the presence of abundant water and carbonate (calcite) and have the nasty capacity to damage masonry severely. The damage process is effected by a considerable increase in the molar volume of the reaction products over the starting materials which causes stress in the masonry and eventually its cracking.

To assess the risk of ettringite and/or thaumsite formation, a simple test in which a sample of "soil mortar" P 1.32 composition (2 volume parts HL, 1 volume part WOPC, 12 volume parts quartz sand + "soil")) ran through several cycles of storage under water for 24 hours and subsequent drying was carried out.

Up to the 9$^{th}$ cycle no development of cracks occurred (**table 5**). However, by chance the sample remained in the water bath for 480 hours before it was taken out and dried again. This time several cracks had developed (**figure 8**) and the test was finished after the 10$^{th}$ cycle.

**Table 5: Water compatibility test with "soil mortar"**

| **Date** | **Cycle** | **Length** [mm] | **Time** [µs] | $v_p$ [km/s] | **Mass** [g] | $WA_{atm}$ [mass %] = **16,2** |
|---|---|---|---|---|---|---|
| | **0** | 91,97 | 54,4 | 1,69 | 139,01 | stored at ambient conditions |
| | | | | | 128,40 | dried for 24h at 70 °C |
| | **1** | | | | 149,30 | stored for 24h under water |
| | | | | | 123,45 | dried for 24h at 70 °C |
| | **2** | | | | 149,06 | stored for 24h under water |
| | | | | | 122,76 | dried for 24h at 70 °C |
| | **3** | | | | 149,08 | stored for 24h under water |
| | | | | | 123,34 | dried for 24h at 70 °C |
| | **4** | | | | 149,13 | stored for 24h under water |
| 02.01.2012 | | 91,97 | 44,4 | 2,07 | 123,32 | dried for 24h at 70 °C |
| | **5** | | | | 148,93 | stored for 24h under water |
| | | | | | 123,28 | dried for 24h at 70 °C |
| | **6** | | | | 149,16 | stored for 24h under water |
| 07.01.2012 | | 91,60 | 43,6 | 2,10 | 123,79 | dried for 24h at 70 °C |
| | **7** | | | | 149,19 | stored for 24h under water |
| | | | | | 123,71 | dried for 24h at 70 °C |
| | **8** | | | | 149,33 | stored for 24h under water |
| 13.01.2012 | | 91,86 | 43,6 | 2,11 | 123,58 | dried for 24h at 70 °C |
| 02.02.2012 | **9** | | | | 150,20 | stored for **480**h under water |
| | | | | | | dried for 24h at 70 °C |
| | **10** | | | | 152,13 | stored for 24h under water |
| 10.02.2012 | | | | | 125,60 | dried for 24h at 70 °C |
| | | | | | | end of test |


**Figure 8: Sample "soil mortar" P 1.32 after 9 cycles in the water compatibility test**

Material from the crack surfaces was scratched off and investigated by X-ray diffractometry and **the formation of thaumasite confirmed** (**figure 9**).

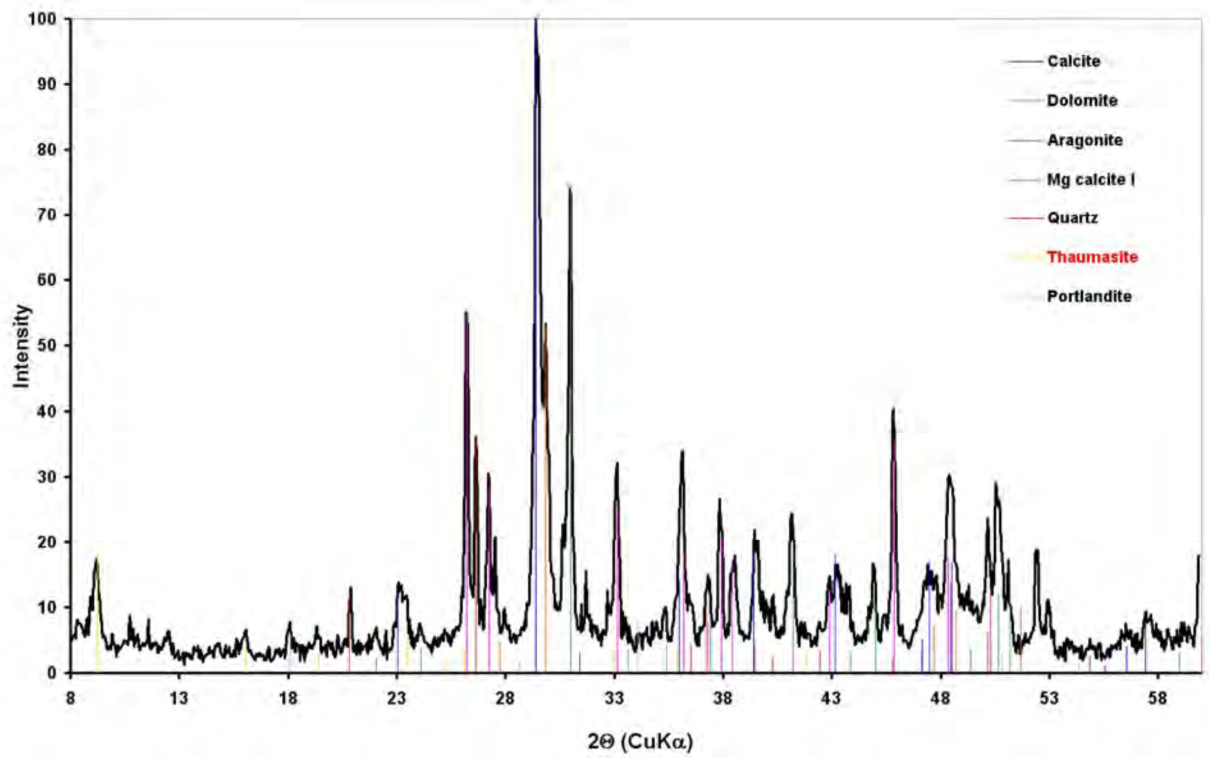



**Figure 9 X-ray diffractogram of "soil mortar" after 9 cycles of storage under water and drying**

A possible explanation of the test result is that the short-term exposure of the "soil mortar" to water and the subsequent rapid drying may not be sufficient to trigger the ettringite and/or thaumasite reaction whereas long-time saturation with water leads to their formation and consequently to the cracking of the mortar.

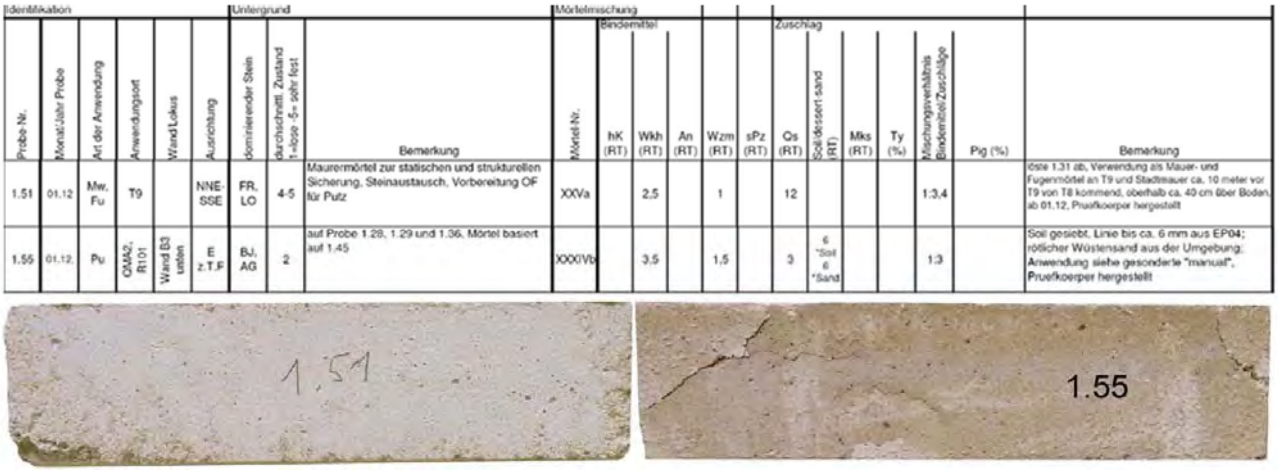
**The test result shows that the risk of ettringite and/or thaumasite formation has to be taken seriously** and makes it necessary to consider where conditions of long-time contact between the mortar and water is given in the masonry of Al Zubarah and to act accordingly. As far as I am informed, no mortar containing WOPC is presently used for the stabilisation and reconstruction work of the foot zone of walls (the remaining Otterbeiner Hydradur NHL is used for this work.). But eventually we will run out of this material and it has to be replaced by something else. **By no means should WOPC-containing mortars be used for work in the foot zone of walls.** The search for alternatives to WOPC has to be continued.

### Epilogue

With the help of the Material Science Unit of Qatar University an appropriate OPC which is available in Qatar will be found.

## 2.3 Mechanical parameters of mortar samples 1.51 and 1.55 (according to list of P. Hofmann)

In December 2011 the first mortar samples were cast into moulds in order to get mortar prisms with the dimensions 16 cm length, 4 cm breadth, and 4 cm height. The scope of mortar testing was enlarged by measuring the uniaxial compressive strength and Young's modulus. **Figure 10** presents the two tested samples 1.51 (wall and repointing mortar) and 1.55 (render).



| Identifikation | | | | | | Untergrund | | | Mörtelmischung | Bindemittel | | | | | Zuschlag | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Probe-Nr. | Monat/Jahr Probe | Art der Anwendung | Anwendungsort | Wand Lokus | Ausrichtung | dominierender Stein | durchschnittl. Zustand 1=lose -5= sehr fest | Bemerkung | Mörtel-Nr. | hK (RT) | Wkh (RT) | An (RT) | Wzm (RT) | sPz (RT) | Qs (RT) | Soil/dessert sand (RT) | Mks (RT) | Ty (%) | Mischungsverhältnis Bindemittel/Zuschläge | Pig (%) | Bemerkung |
| 1.51 | 01.12 | Mw, Fu | T9 | | NNE-SSE | FR, LO | 4-5 | Maurermörtel zur statischen und strukturellen Sicherung, Steinaustausch, Vorbereitung OF für Putz | XXVa | | 2,5 | | 1 | | 12 | | | | 1:3,4 | | löste 1.31 ab, Verwendung als Mauer- und Fugenmörtel an T9 und Stadtmauer ca. 10 meter vor T9 von T8 kommend, oberhalb ca. 40 cm über Boden, ab 01.12, Pruefkoerper hergestellt |
| 1.55 | 01.12 | Pu | OMA2, R101 | Wand B3 unten | E z.T.F | BJ, AG | 2 | auf Probe 1.28, 1.29 und 1.36, Mörtel basiert auf 1.45 | XXXIVb | | 3,5 | | 1,5 | | 3 | 6 *Soil 6 *Sand | | | 1:3 | | Soil gesiebt, Linie bis ca. 6 mm aus EP04; rötlicher Wüstensand aus der Umgebung; Anwendung siehe gesonderte "manual", Pruefkoerper hergestellt |



**Figure 10: Mortar samples 1.51 and 1.55**

Before the samples were destroyed in the course of the compressive strength test they were used for measuring Young's modulus by a method described by Erfurt and Krompholz (1996). With an ultrasonic wave generator longituidinal and quasi-longitudinal waves are excited in prismatic or rod-like samples. The measurement is recorded by an oscilloscope and the resulting oscillogram is evaluated with respect to the onset of the l-wave and the resonance frequency of the sample (**figure 10**). Young's modulus is equal to two times the product of sample length, sample density and resonance frequency.

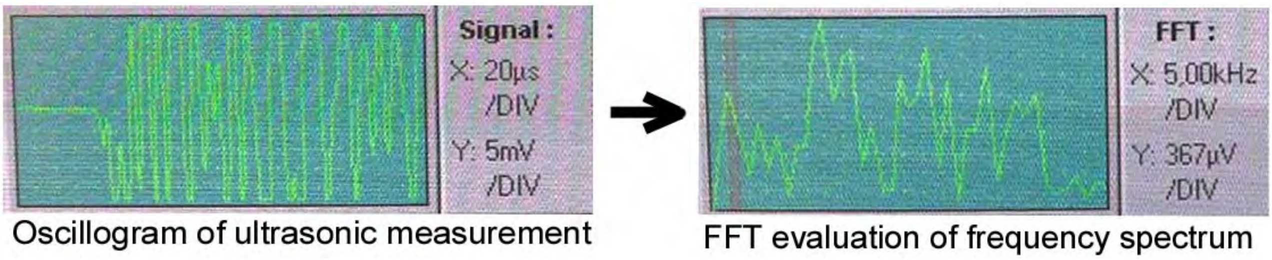




**Figure 11: Oscillogram of us measurement on sample 1.55 and frequency spectrum**

The test results for the mortar samples 1.51 and 1.55 are summarized in **table 6**.

**Table 6: Mechanical parameters of mortar samples 1.51 and 1.55**

| Sample | Length [cm] | Resonance frequency [kHz] | Density [g/cm³] | $v_p$ [km/s] | Young's modulus [N/mm²] | Compressive Strength [N/mm²] |
|---|---|---|---|---|---|---|
| Mortar 1.51 | 16,0 | 4,883 | 1,79 | 1,781 | 4,42 | 1,8 |
| Mortar 1.55 | 16,0 | 4,883 | 1,76 | 2,13 | 4,36 | 3,2 |

## 2.4 Analyses of plasters from the old village Jumail

Bernadeta Schäfer from the team surveying the old villages NE of Al Zubarah handed in two plaster samples from buildings in Jumail for the investigation of the binding material and the general composition. Both samples were analyzed by X-ray powder diffraction and optical microscopy of thin sections. The results are documented in **figure 12**.

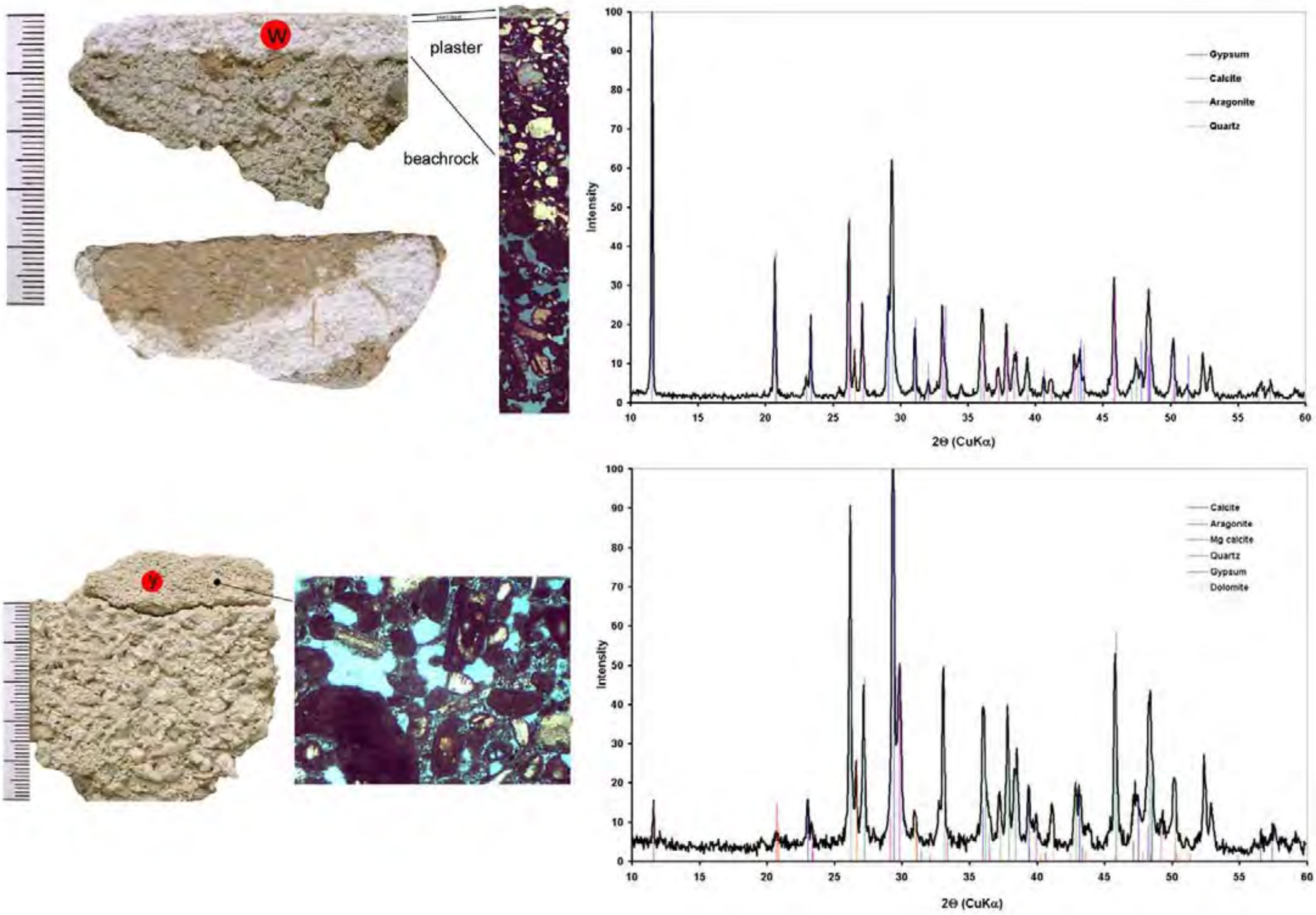



**Figure 12: Different renders on beachrock building stones from the old village Jumail**

The white and 7 mm thick render on a beachrock (upper sample in figure 11) is coated by a thin brownish paint layer and based on anhydrite as principal binding material. In the top view photograph are two fibres recognizable which were probably used as reinforcement of the plaster. The aggregate consists of shell debris (aragonite) and quartz grains. The pure (magnesium-free) calcite is most probably a part of the binding material (anhydrite mortar with addition of lime). The thin section shows that the fabric of the mortar is much less porous than the underlying beachrock in which large blue-dyed pores stand out clearly against the dark matrix formed by loosely cemented shell debris.

This white render must not be mixed up with a white render underneath a yellow grey render at Al Zubarah fort which is a lime-based render.

The yellow grey and up to 15 mm thick render on a beachrock was prepared with lime as binding material. The aggregate consists of crushed shells or beachrock (aragonite, Mg calcite) and some dolomite and quartz. There is also a little bit of gypsum present in the sample but it is assumed that it is of secondary rather than of primary origin. The fabric of the lime-based render is characterized by a loose packing of aggregate grains stabilized by calcite cement and pores in between the matrix-forming particles. The pores have about the same size as the matrix particles and add up to 40 – 45 volume percent porosity.

## 3. Production and application of anhydrite plaster in Al Zubarah

According to the local building tradition the walls of buildings at Al Zubarah were internally and externally coated with gypsum plaster (**figure 13**).

**Figure 13: Decorated wall plaster, South Field, Room 005 Wall c**

The raw material for the preparation of the plaster, namely gypsum, is ubiquitous on the peninsula of Qatar. Especially in the vicinity of Al Zubarah gypsum, related to the sabkha facies, can easily be collected. The excavations at Freyha led to the discovery of a double chamber construction which is regarded as a small kiln for the burning of gypsum (**figure 14**).

**Figure 14: Double chamber construction at Freyha excavation site**

The conservation of architectural remains of Al Zubarah city should be done as authentically as possible and therefore anhydrite plaster must play an important role in this work. Anhydrite plaster had been produced by QMA in the past but the plant is not working at the moment. Therefore the whole process from the burning of gypsum to the application of the anhydrite plaster to a test wall in the North Field was carried out in a sort of experimental archaeology project. The experiments started in January 2012 with a small and simple device for the burning of gypsum in order to study the efficiency of the process and to get samples for the X-ray diffraction analysis of the reaction products.

The first device consisted of an about 35 cm long steel tube with an inner diameter of about 6 cm which was closed at the bottom with a wire mesh. The mesh width was about 5 – 8 mm. To keep the tube in an upright position three supporting legs were welded on the outer surface at 120 ° distance. The legs were made long enough to put a gas burner under the wire mesh at the lower end of the tube. The tube was filled with a mixture of gypsum and charcoal crushed to the size of a hazelnut. The ratio of gypsum to charcoal pieces was about 3 to 5. The ignition of the charcoal lying on the wire mesh was achieved by the gas burner under the tube. To enforce the smouldering of the charcoal above the bottom layer compressed air was gently blown through the wire mesh at the bottom (**figure 15**). A complete burning out of the filling required about half an hour.


**Figure 15: Tube-like experimental kiln for the burning of gypsum**

After burning out the filling was taken from the device in three consecutive zones I - III. The gypsum pieces of zone I were completely white after the burning and could easily be crushed between the fingers. A part of this white material was mixed with water and cured to a grey-yellowish, hard mass barely scratchable by a fingernail (**figure 16**). The grey-yellowish colour is due to the admixture of charcoal particles to the anhydrite powder.

The raw gypsum, the firing products of each zone and the hardened anhydrite mortar were investigated qualitatively by X-ray diffraction (**figure 17**). The samples were labelled as A_00 raw gypsum, A_01 tube filling from zone I, A_01 02 tube filling from zone I in a second experiment, A_02 tube filling from zone II, and A_03 hardened anhydrite mortar. **Table 7** summarizes the results. The phases in the system $CaSO_4$ – $H_2O$ are compiled in **table 8**.

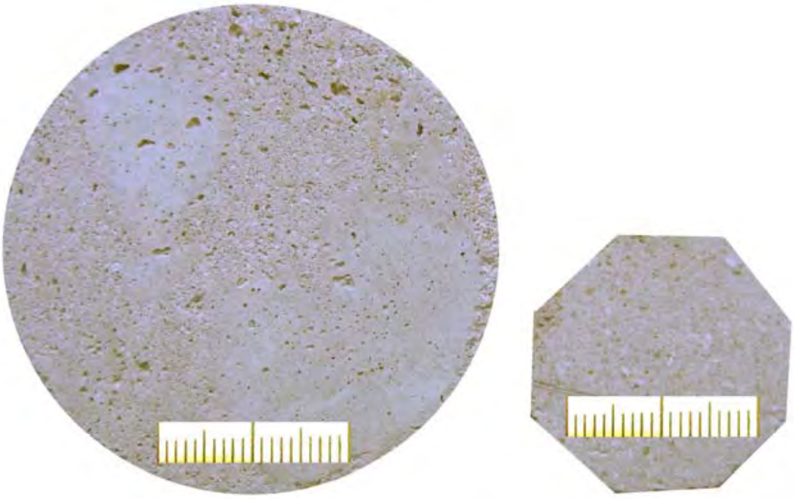


**Figure 16: Samples of cured anhydrite mortar**

**Table 7: Phase compositions of raw material, firing products, and hardened anhydrite plaster sample**

| Sample | Description | Phase composition |
|---|---|---|
| A_00 | raw material | gypsum with a trace of calcite |
| A_01 | material from kiln zone I | anhydrite, calcite, quartz, bassanite |
| A_01 02 | material from kiln zone I | anhydrite, lime, quartz |
| A_02 | material from kiln zone II | gypsum |
| A_03 | hardened anhydrite mortar | gypsum, anhydrite, calcite, quartz |

An interpretation of the phase identification by X-ray diffraction runs as follows:

1. The raw gypsum used was fairly pure due to careful elimination of adhering impurities. Only traces of calcite were identified.

2. The phase assemblage of sample A_01 contained no more gypsum which means that a complete conversion of gypsum to anhydrite was achieved. Traces of bassanite indicate that the firing temperature at the upper end of zone I did not exceed 150 – 180 °C. Most probably part of the anhydrite obtained is of modification III. The presence of calcite indicates that the temperature nowhere in zone I exceeded 800 °C.

3. The phase assemblage of sample A_01 02 contains also anhydrite as the principal phase. However, there are no more traces of bassanite and calcite. Instead lime (CaO) occurs as a new phase. This result shows that with an improved ventilation temperatures above 800 °C can be achieved. The anhydrite in this phase assemblage will be of modification II.

4. Sample A_02 shows that in the first experiment the temperature in zone II was not high enough to transform gypsum either to bassanite or anhydrite.

5. The hardened anhydrite mortar consists mostly of gypsum and contains little anhydrite. The curing process of the self-made anhydrite mortar produced much better results than the trials with commercial products from the Suedharzer Gipswerke GmbH.

**Table 8: Phases in the system $CaSO_4$ – $H_2O$**

| | |
|---|---|
| $CaSO_4 \cdot 2H_2O$<br>↓<br>150°C–180°C<br>↓ | Natural gypsum – crystals of plate habit. Spatial structure of the compound comprises double layers of $CaSO_4$ divided by parallel double layers of water particles. $Ca^{2+}$ ions in $CaSO_4$ layers are set alternately with $SO_4$ tetrahedrons. Crystalline water particles interact with $Ca^{2+}$ ions and form hydrogen bonds with oxygen atoms of $SO_4^{2-}$ groups. Weak reaction between water particles in the layers is the reason for perfect cleavage of raw gypsum in this plane. |
| $CaSO_4 \cdot ½H_2O$<br>↓<br>170°C–250°C<br>↓<br>$CaSO_4$ III<br>↓ | Gypsum hemihydrate has two well-soluble variations: alpha and beta. α-hemihydrate – obtained during calcination in steam atmosphere; columnar crystals. β-hemihydrate – obtained in dry calcination; crystals of no clear habit, plate-shaped aggregates of fibrous or scaly structure are formed. Both forms have crystal lattice identical with that of gypsum dihydrate. β variation, due to a larger specific surface, dissolves more easily and thus binds faster, but its products have lower strength compared to α-made ones. |
| 350°C–600°C<br>↓<br>$CaSO_4$ II<br>↓<br>800°C–1000°C<br>↓ | Anhydrite III – occurrs in two variations, α and β, retaining the crystal structure of gypsum hemihydrate. When in humid air, it absorbs water from the environment; highest solubility in water among all described here sulphates. Further heating of anhydrite III causes the transformation of its crystal structure (the distance between lattice points is reduced) into anhydrite II structure. |
| $CaSO_4$ II + ~5%CaO<br>↓<br>1200°C<br>↓<br>$CaSO_4$ I<br>↓ | Anhydrite II – identical with natural anhydrite. Crystal structure of the compound is similar to NaCl. $SO_4^{2-}$ ions are clustered and spaced uniformly with $Ca^{2+}$ ions in all directions. Such structure makes anhydrite II the strongest among all gypsum types, of the highest specific density and sparingly soluble. Crystals are prism-shaped (Fig. 9.3). Comparison of anhydrite II with gypsum dihydrate reveals a weakening influence of crystalline water on gypsum crystal structure, and thus, on mechanical properties of the material. |
| *1350°C*<br>*$CaSO_4$/CaO*<br>*blend melting* | Estrich gypsum (anhydrous gypsum plaster) is formed in a partial decomposition of $CaSO_4$ II → CaO + $SO_2 \cdot ½ H_2O_2$ |

With the experience of the first experiments a second tubelike kiln with a volume almost ten times larger than the first one was built. It had a height of 51 cm and an inner diametre of 15,5 cm. Instead of blowing compressed air into the kiln the necessary draught for the combustion of the charcoal was achieved by mounting a 150 cm long funnel on top of the kiln (**figure 18**).

The experiments with the larger kiln were used for balancing the input and output of materials. The kiln was charged with 1547 g charcoal and 2243 g gypsum. After the burning a total of 1608 g burnt gypsum was handpicked from the filling which corresponds to 90,7 % of the theoretical yield (**figure 19**). However, it has to remarked that this excellent result is due to the small scale operation of the gypsum burning with the raw material carefully selected by hand (**figure 20**).

Material from the different kiln zones was again analysed by X-ray diffraction in order to check the internal temperature by the phase assemblages (**table 9**, **figure 21**). The burnt gypsum from two runs (3641 g) was used for the plastering of a 30 x 70 cm² test area at the wall of a building in the North Field (**figure 22**).

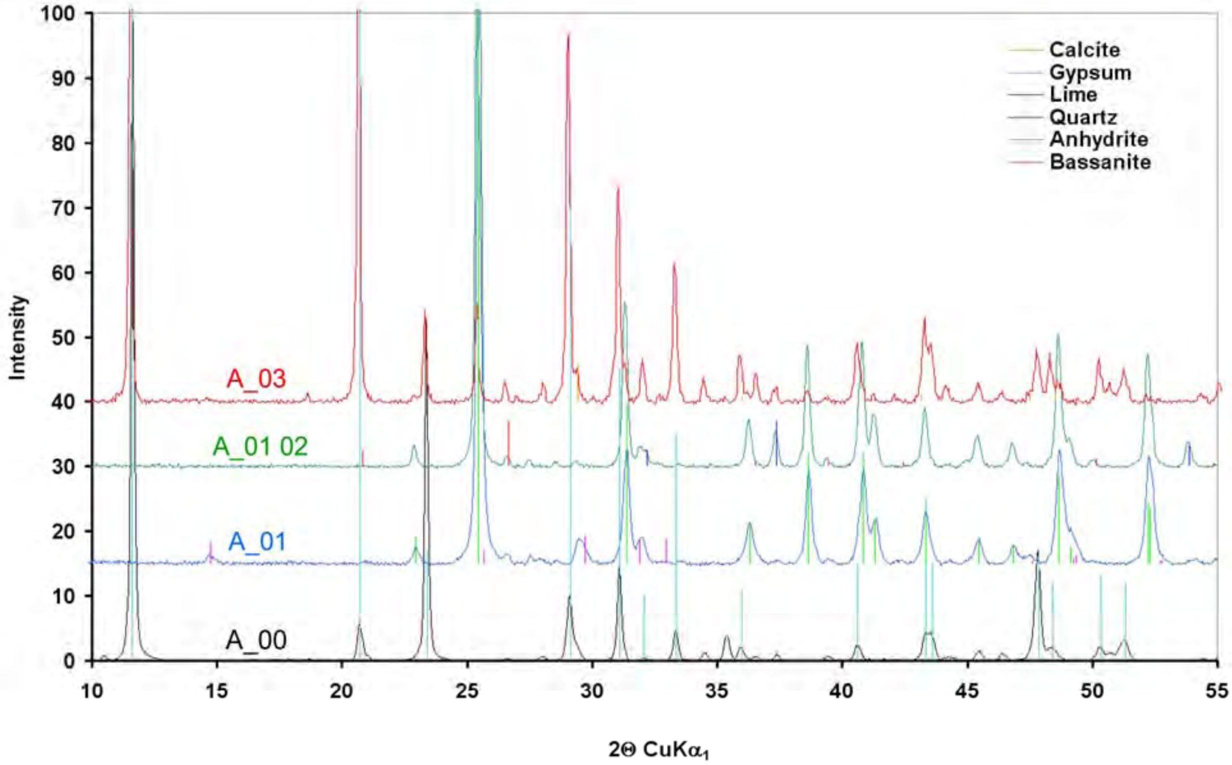



**Figure 17: Reaction products of gypsum burning and anhydrite plaster hardening with small kiln and the use of compressed air**

**Figure 18: Large kiln with funnel mounted on top**


**Figure 19: Kiln filling from the transition of zone III** (left) **to zone II**



**Figure 20: Selecting, weighing and sieving of raw material**

**Table 9: Phase compositions of raw material, firing products, and hardened anhydrite plaster sample**

| Sample | Description | Phase composition |
|---|---|---|
| B-01 | material from kiln zone I | anhydrite |
| B-02 | material from kiln zone II | anhydrite |
| B-03 | material from kiln zone III | bassanite, dolomite |
| B-04 | anhydrite mortar for plastering | anhydrite, bassanite |
| B-05 | hardened anhydrite mortar | gypsum, anhydrite |

The interpretation of the phase identification by X-ray diffraction is as follows:

1. The gypsum lumps in the zones I and II (B-01 and B-02) were completely transformed to anhydrite.
2. The gypsum in zone III (B-03) was transformed to bassanite. This means that the temperature at the upper end of the kiln did not exceed 100 – 120 °C.
3. The material used for the plaster sample at the test wall in the North field (B-04) was a mixture of anhydrite and bassanite.
4. Of the two reactive components of the plaster mortar bassanite reacted completely and anhydrite partly with water to form gypsum. The findings by X-ray diffraction analysis were corroborated by the optical microscopy of a thin section of the hardened gypsum plaster (**figure 23**).

The principal difference in the results of experimentation with the two kilns was that the injection of compressed air led to a quick combustion of the charcoal at high temperatures while the combustion supported by the draught due to the funnel took place at lower temperatures and lasted much longer. The temperature profile was very steep in both cases with a hot zone (I) at the bottom and a fairly cold zone (III) at the top of the kiln. The presence of bassanite in zone III of the large kiln, however, showed that this zone was hotter than the corresponding zone III in the small kiln which contained unalterd gypsum.

The results of the test production and application of anhydrite mortar are very encouraging. It should be possible to transfer the experience to a plant which is big enough to produce sufficient amounts of anhydrite which can be used as plaster mortar. In cooperation with the Materials Science Unit at Qatar University a quality control programme could be installed.

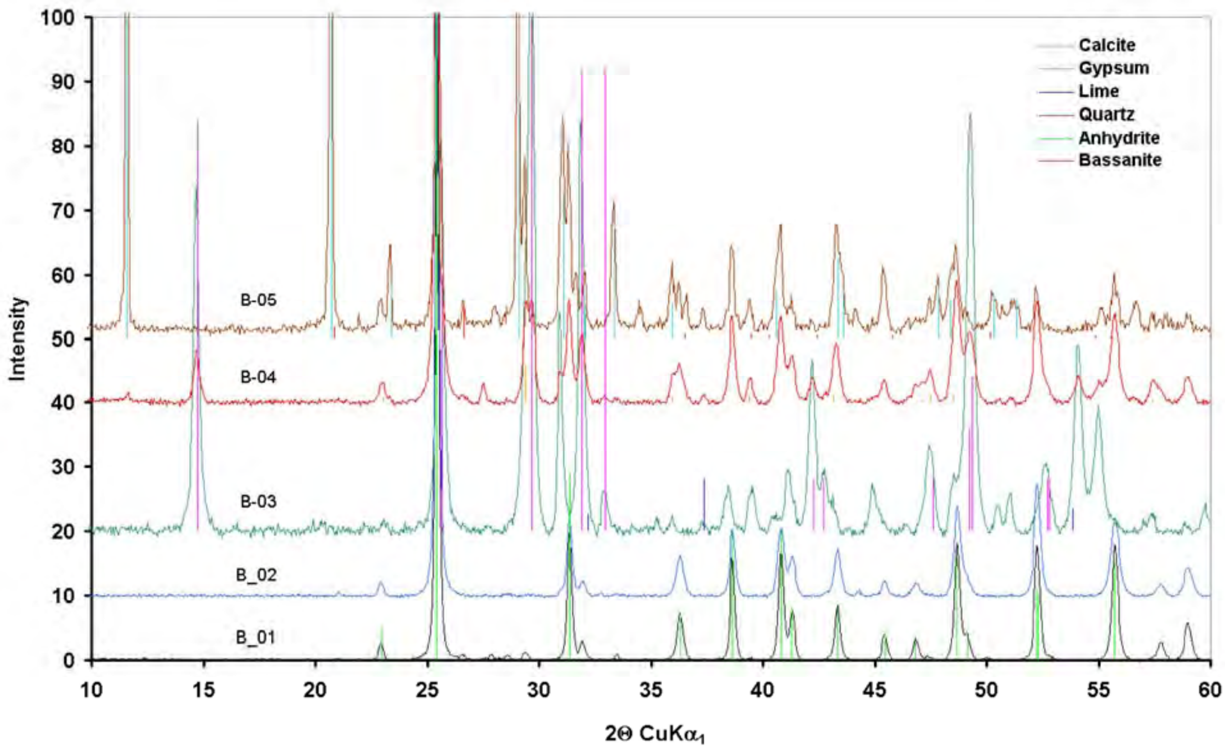



**Figure 21: Reaction products of gypsum burning In the large kiln and gypsum plaster from the test wall in the North Field**

**Figure 22: Gypsum plaster at test wall in the North Field**

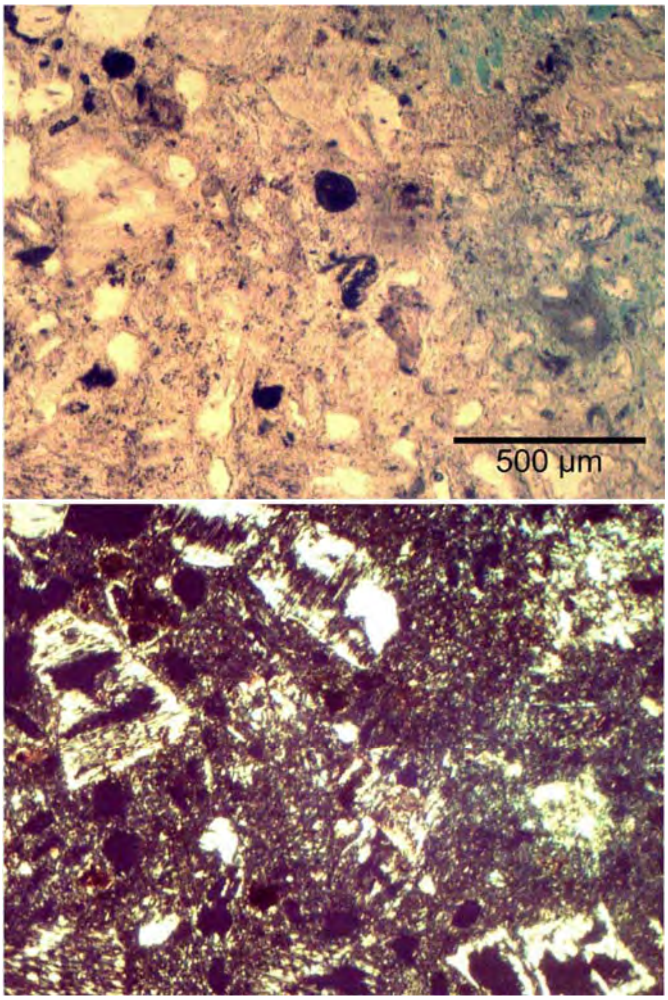



**Figure 23: Thin section photographs of gypsum plaster shown in figure 16**
**Top: plane-polarized light, bottom: crossed nicols**

## 4. Consolidation test on gypsum plaster with Xilan

Tests for the consolidation gypsum plaster with a flaky surface were performed with Xilan® (Consolidas Kunst und Kulturgut GmbH Alte Ziegelei 96110 Schesslitz) which is mixture of two functionalized silanes in ethanol as solvent. The amine-functionalized alkyltrialkoxysilane component 1 (APTS) and the epoxy-functionalized alkyltrialkoxysilane component 2 (GLYMO) react after the evaporation of the solvent in a first step with the elimination of alcohol and the formation of Si-O-Si bonds in a 3D silicate network. Simultaneously, the reaction of APTS (or the $OH^-$ ions formed in the presence of water) with GLYMO leads to the formation of a chains in the form of oligo(polyether) structures of the epoxy-functionalized component The reaction mechanisms of the components at the pore walls include the condensation of the $Si(OR)_x$ groups as well as the reaction of the amine group with transition metal ions in the rock. The optimal consolidation requires a perfect interplay of all the reaction steps and mechanisms which are controlled by the composition of the consolidation fluid and the conditions of evaporation of the solvent ethanol.

Prior to the application in the field tests with Xilan® were made in the laboratory. The consolidation fluid was applied to the surface of the gypsum plaster samples with a hypodermic syringe as long as the fluid was sucked into the porous structure. The effect of consolidation was monitored by measuring the ultrasonic velocity of the sample before and after the treatment. The consolidation effect is positively correlated with an increase of the ultrasonic velocity (**table 10**).

**Table 10: Ultrasonic velocities of gypsum plasters before and after treatment with Xilan®**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Sample 1** | | **Length** [mm] | **Time** [µs] | $v_p$ [km/s] | **Mass** [g] | **Quantity** |
| | | | | | | [kg/m²] |
| Direction 1 | **before** | 49,32 | 20,0 | **2,47** | 42,24 | 1,0 |
| Direction 2 | **treatment** | 53,55 | 22,0 | **2,43** | | |
| | | | | | 44,88 | |
| 01.01. 12 | **after** | | | | 42,66 | |
| 03.01. 12 | **treatment** | 49,32 | 18,6 | **2,65** | 42,63 | |
| | | 53,55 | 19,6 | **2,73** | | |
| | | | | | | |
| **Sample 2** | | **Length** [mm] | **Time** [µs] | $v_p$ [km/s] | **Mass** [g] | **Quantity** |
| | | | | | | [kg/m²] |
| Direction 1 | **before** | 85,86 | 31,4 | **2,73** | 86,45 | 0,9 |
| Direction 2 | **treatment** | 55,68 | 19,4 | **2,87** | | |
| | | | | | 90,63 | |
| 07.01. 12 | **after** | | | | 87,00 | |
| 08.01. 12 | **treatment** | 85,86 | 31,2 | **2,75** | 86,94 | |
| | | 55,68 | 19,4 | **2,87** | | |
| | | | | | | |
| **Sample 3** | | **Length** [mm] | **Time** [µs] | $v_p$ [km/s] | **Mass** [g] | **Quantity** |
| | | | | | | [kg/m²] |
| Direction 1 | **before** | 45,74 | 18,8 | **2,43** | 43,49 | 1,4 |
| Direction 2 | **treatment** | 44,77 | 18,8 | **2,38** | | |
| | | | | | 46,38 | |
| 07.01. 12 | **after** | | | | 43,92 | |
| 08.01. 12 | **treatment** | 45,74 | 18,2 | **2,51** | 43,85 | |
| | | 44,77 | 18,0 | **2,49** | | |

The results in table 10 underline the importance of a perfect interplay of all the reaction steps and mechanisms in order to obtain an optimum consolidation result. The treatment of sample 2 led to no increase of the ultrasonic velocity what can be interpreted either as a failed process or the selection of an inappropriate sample which needed no consolidation. The initially high ultrasonic velocities of this sample argue for the second possibility.

The colour of gypsum plaster surfaces treated with Xilan® is slightly darker than the original one (**figure 23**).


**Figure 24: Gypsum plaster surface before** (left) **and after treatment with Xilan®. Note the slightly darker colour of the treated sample.**


**Figure 25: Consolidation test with Xilan® at wall plaster (gypsum) in room with mastaba at EP 04**

A field test with Xilan® was carried out on the right wall (seen from the entrance) of a room with a mastaba (date press) at EP 04. The gypsum plaster was crumbly and flaky and the surface definitely required a consolidation. Xilan® was mixed at the camp from the two components which were brought to Al Zubarah personally. **[The personal transport of Xilan® is not recommended as the standard procedure of importation because the accompanying person runs a high risk of either being requested strongly by the carrier to leave the fluid containers behind or getting problems with security authorities. Although the components are not highly inflammable they are definitely not harmless chemicals and should be treated with appropriate care.]**

The application of Xilan® to the wall took place in the evening hours (4.30 – 5.30 pm) and was done with a brush because a fitting spray bottle was not available. The outdoor temperature was 27 °C. The photo collage in **figure 25** shows that the ethanol evaporated within less than 1 hour although there was still a faint odour of ethanol perceivable on the next day. About one hour after the application of Xilan® a fine drizzle of water was sprayed on the test area. Since the author of this report left Al Zubarah two days after the test a rating of the result would be too early now and will be done at the end of may 2012. However, a haptic test of the surface on the next day gave the impression that no particles were removed by moving a finger over the flaky surface. The environmental conditions for a successful application of Xilan® are undisputedly better in a restorer's workshop than at the excavation site.

## 5. Delivery and installation of analytical equipment for on-site laboratory

In January 2012 some laboratory equipment comprising a pair of scales and a device for measuring the electrical conductivity and total dissolved solids (TDS) of aqueous solutions together with test strips and chemicals for determining the sulphate, nitrate, and chloride contents of building material samples were brought to the camp at Al Zubarah. Paul Hofmann and Karl were instructed by Robert Sobott how to use the equipment and to evaluate the measured data (**figure 26**).

**Figure 26: Paul evaluating of data** (left) **and Karl measuring the electric conductivity of a sample**

## 6. Identification of rocks and objects made of stone in the find magazine

Among the many objects which were found at the various excavation places is a fairly large number of tools and commodities which were made of stones that are not to be found on the peninsular of Qatar. To these objects belong diving weights (**figure 27**) which are made of hematite-magnetite ore, metamorphosed peridotite, barite (**figure 28**), and other not yet identified stone materials. Since these rocks do not occur in Qatar they must have been imported to Al Zubarah. Potential sources from a petrographical-mineralogical point of view are Iran (barite, hematite-magnetite, ultrabasic rocks) and Oman (peridotite, ultrabasic rocks). The tracing of the points of origin of these special rocks would contribute to the understanding of trade routes and relations of the people of Al Zubarah with neighbouring countries.

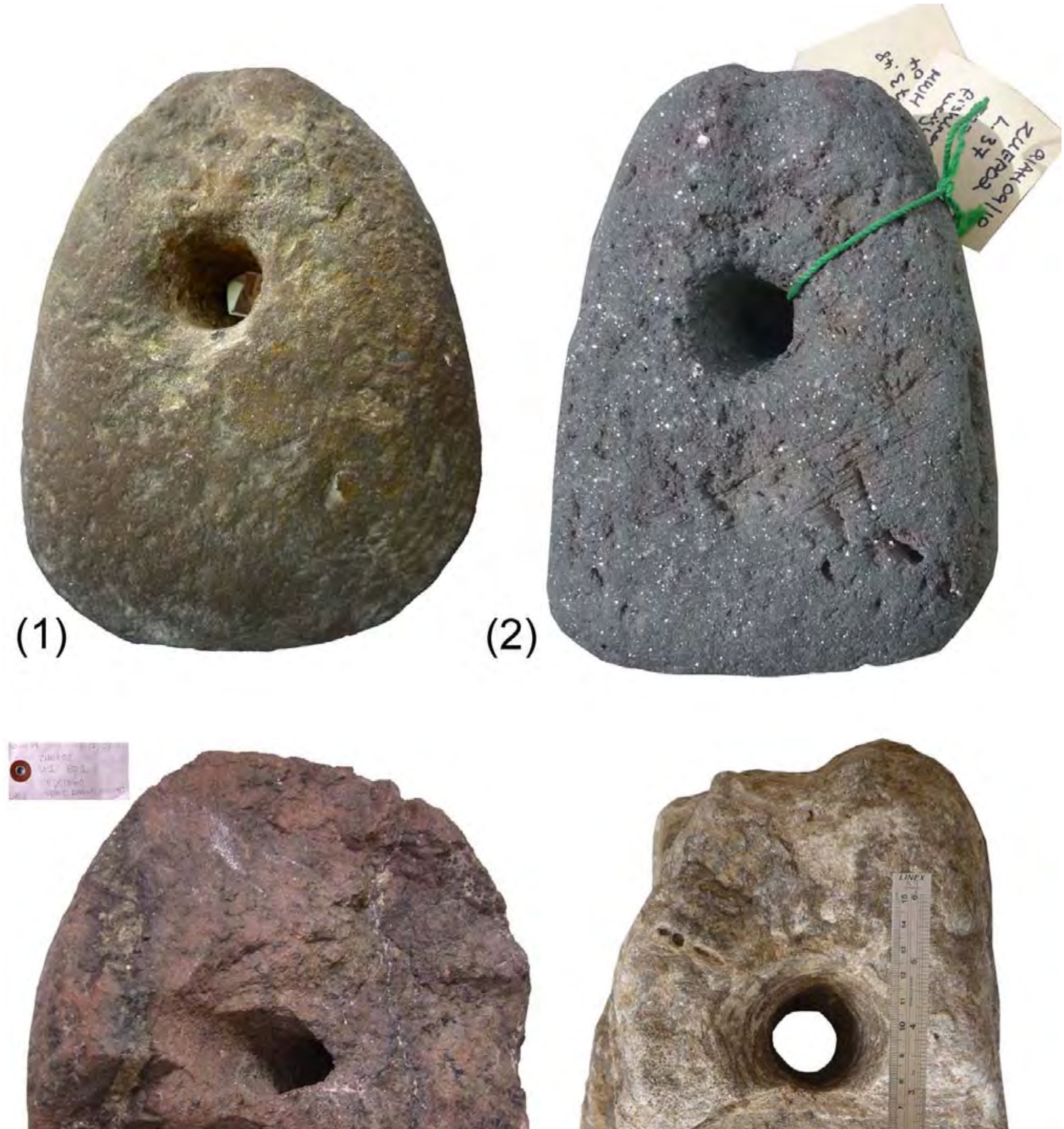



**Figure 27: Stone diving weights made of different materials. From top left clockwise:**
**(1) unidentified rock material, (2) hematite-magnetite-(goethite), (3) barite-dolomite,**
**(4) partly metamorphosed peridotite (olivine, lizardite)**

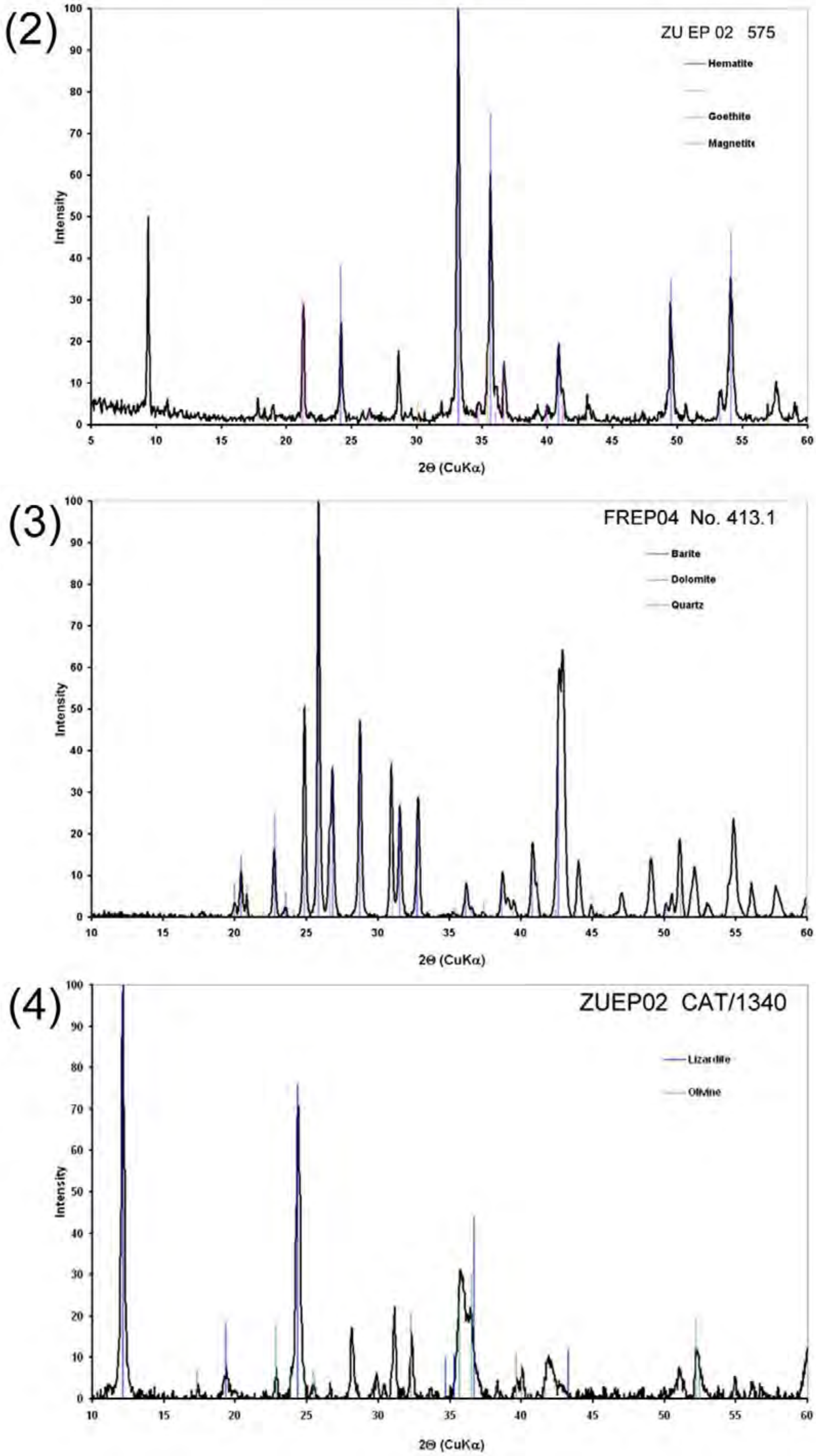



**Figure 28: X-ray diffractograms of stone diving weights 2 – 4 in figure 26**

The collection of „odd stones“ also comprises a lump of dolomite (**figure 29**) which is speckled by black and green dots which turned out to be tenorite (black copper(**II**) oxide) and atacamite, $Cu_2(OH)_3Cl$. The two copper minerals are oxidation minerals of primary copper (**I**) sulphide, chalcocite $Cu_2S$. The peculiar rock is nothing less than a low-grade copper ore ! And again, it would be most interesting to have an answer to the questions where does it come from and what was it used for?

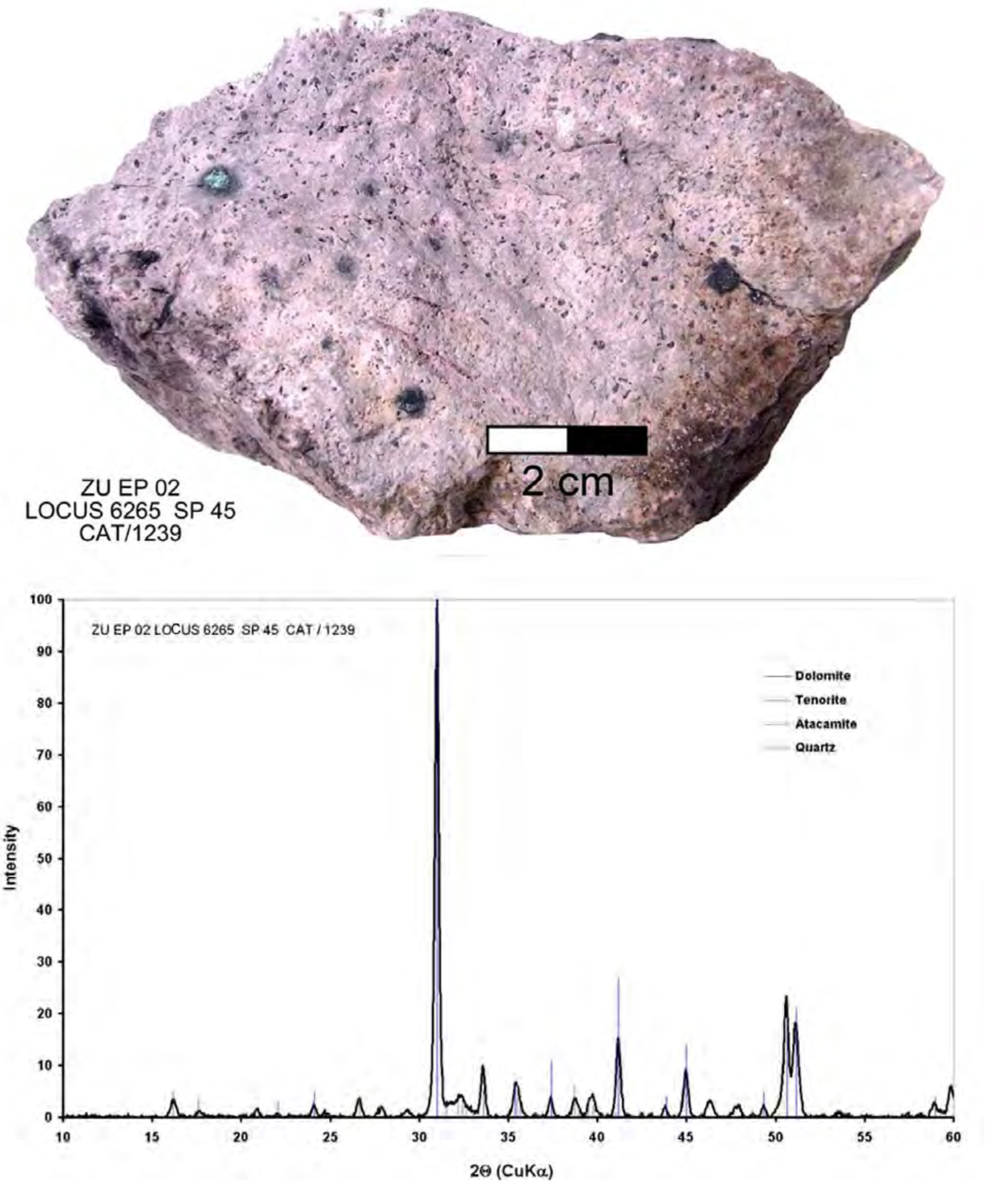



**Figure 29: X-ray diffractogram (EU EP 02 Loc. 6285 SP 45 CAT 1239)**

Apart from the diving weights and odd stones other objects made of stone were looked at and, whenever possible, identified (**table 11**). In some case the identification was supported by X-ray diffraction analysis.

**Table 11: Stone objects in the find magazine**

| No. | CAT No. | Area | Locus | Space | Find Object | Material | Comments |
|---|---|---|---|---|---|---|---|
| 1 | 1003 | ZU EP 01 | 1853 | | 1 | limestone | |
| 2 | 1004 | ZU EP 01 | 1714 | | | hematite | |
| 3 | 1025 | ZU EP 01 | 1762 | | 3 | greenstone | pestle |
| 4 | 1045 | ZU EP 01 | 7078 | 183 | 1 | hematite | |
| 5 | 1087 | ZU EP 01 | 7310 | | 1 | dolomite | grinder |
| 6 | 1178 | ZU EP 01 | 7540 | | 2 | quartz schist | fine-grained |
| 7 | 1186 | ZU EP 01 | 7531 | 188 | | hbl-plg rock | see Z 9 |
| 8 | 1121 | ZU EP 01 | 7534 | 188 | 3 | dolomite | limestone ball |
| 9 | 1335 | ZU EP 01 | 1106 | | 1 | hematite | |
| 10 | | ZU EP 01 | 7592 | 198 | | basalt | |
| 11 | 556 | ZU EP 02 | 2014 | | | specularite | |
| 12 | 571 | ZU EP 02 | | | | | |
| 13 | 573 | ZU EP 02 | 2014 | | | hematite | |
| 14 | 575 | ZU EP 02 | 2014 | | | hematite | |
| 15 | 576 | ZU EP 02 | 2014 | | | hematite | fine-grained |
| 16 | 577 | ZU EP 02 | 2014 | | | hematite | |
| 17 | 1023 | ZU EP 02 | 2787 | | 2 | ultrabsite | see 1340, 1341 |
| 18 | 1163 | ZU EP 02 | 6633 | 5 | 1 | "greenstone" | |
| 19 | 1239 | ZU EP 02 | 6265 | | 5 | | see XRD |
| 20 | 1248 | ZU EP 02 | 6822 | 89 | | quartz schist | see 1178 |
| 21 | 1331 | ZU EP 02 | 2014 | | | hematite | |
| 22 | 1332 | ZU EP 02 | 2014 | | | hematite | |
| 23 | 1334 | ZU EP 02 | 2014 | | | hematite | |
| 24 | 1336 | ZU EP 02 | 37 | | 2 | hematite | |
| 25 | 1339 | ZU EP 02 | 2001 | | 1 | hematite | salt encrusted |
| 26 | 1340 | ZU EP 02 | 1 | | 1 | ultrabsite | see 1341 |
| 27 | 1341 | ZU EP 02 | 2014 | 7 | 7 | ultrabasite | |
| 28 | 1359 | ZU EP 02 | 6626 | | 2 | limestone | fossiliferous |
| 29 | 1373 | ZU EP 02 | 6745 | 59 | 63 | limestone | |
| 30 | | ZU EP 02 | 6835 | 61 | | calcite XX | |
| 31 | 1152 | ZU EP 04 | 4508 | 3025 | 29 | dolomite | limestone ball |
| 32 | 1245 | ZU EP 04 | 4180 | 3018 | 2 | | "arrow" |
| 33 | | ZU EP 04 | 4510 | 3024 | 16 | hematite | coarsely crystalline |
| 34 | 1144 | ZU EP 10 | 10034 | | 2 | aeolianite | weight stone |
| 35 | 1179 | ZU EP 10 | 10090 | | 1 | dolomite | |
| 36 | 200 | FR EP 04 | 819 | | 2 | dolomite | limestone ball |
| 37 | 232 | FR EP 04 | 823 | | 2 | aeolianite | pierced stoneweight |
| 38 | 233 | FR EP 04 | 934 | | 1 | aeolianite | |
| 39 | 355 | FR EP 04 | 1658 | | 1 | basalt ? | |
| 40 | | FR EP 04 | 399 | 8 | | basaltic rock | |
| 41 | | FR EP 04 | 1058 | | 6 | flint | |
| 42 | | FR EP 04 | 1321 | | | dolomite | |
| 43 | | FR EP 04 | 1671 | | | calcite X | |
| 44 | | FR EP 04 | | | | | |
| 45 | | QIAH 277 | Survey unit 586 | | 3 | hbl-plg rock | see Z 9 |

Other interesting samples were the green and blueish oxidation products on a copper coin and a small piece from the remnants of supposed leather bag which contained a mixture of a yellow earth and fine-grained gold-glittering particles.

The X-ray diffractogramm in **figure 30** shows that the principal oxidation product on the copper coin is green orthorhombic atacamite, the divalent basic copper chloride $Cu_2(OH)_3Cl$. The blueish oxidation product turned out to be chalconatronite, $Na_2Cu(CO_3)_2{*}3H_2O$. Monovalent red copper oxide, $Cu_2O$ (cuprite), is the primary oxidation product which reacts with seawater containing sodium chloride and dissolved carbon dioxide and oxygen to atacamite and chalconatronite.

$$2.5\ Cu_2O + (4.5\ H_2O + 0.5\ O_2 + 2\ CO_2) + 2\ NaCl \rightarrow Na_2Cu(CO_3)_2{*}3H_2O + 2\ Cu_2(OH)_3Cl$$

It is interesting to note that $Cu_2(OH)_3Cl$ occurs in three modifications with different crystal structure. The other two minerals are paratacamite (trigonal) and botallackite (monoclinic). In an environment dominated by sulphate instead of chloride ions the occurrence of green brochantite, $Cu_4[(OH)_6|SO4]$, and green antlerite, $Cu_3[(OH)_4|SO4]$, could be expected.

The investigation of the contents of the leather bag **(figure 31**) proved that the fine-grained gold-glittering particles were pyrite, $FeS_2$, and that the yellow earth consisted of gypsum and jarosite, $KFe_3[(OH)_6|(SO_4)_2]$. According to the EDX analysis the jarosite contains practically no sodium and is a jarosite proper and not a natrojarosite $(Na,K)Fe_3[(OH)_6|(SO_4)_2]$.

The SEM investigation of a sample with the yellow earth attached to the remnants of leather (?) yielded a fibrous structure for the supposed organic material. The jarosite shows small rhombohedral crystals with about 10 µm long crystal edges.

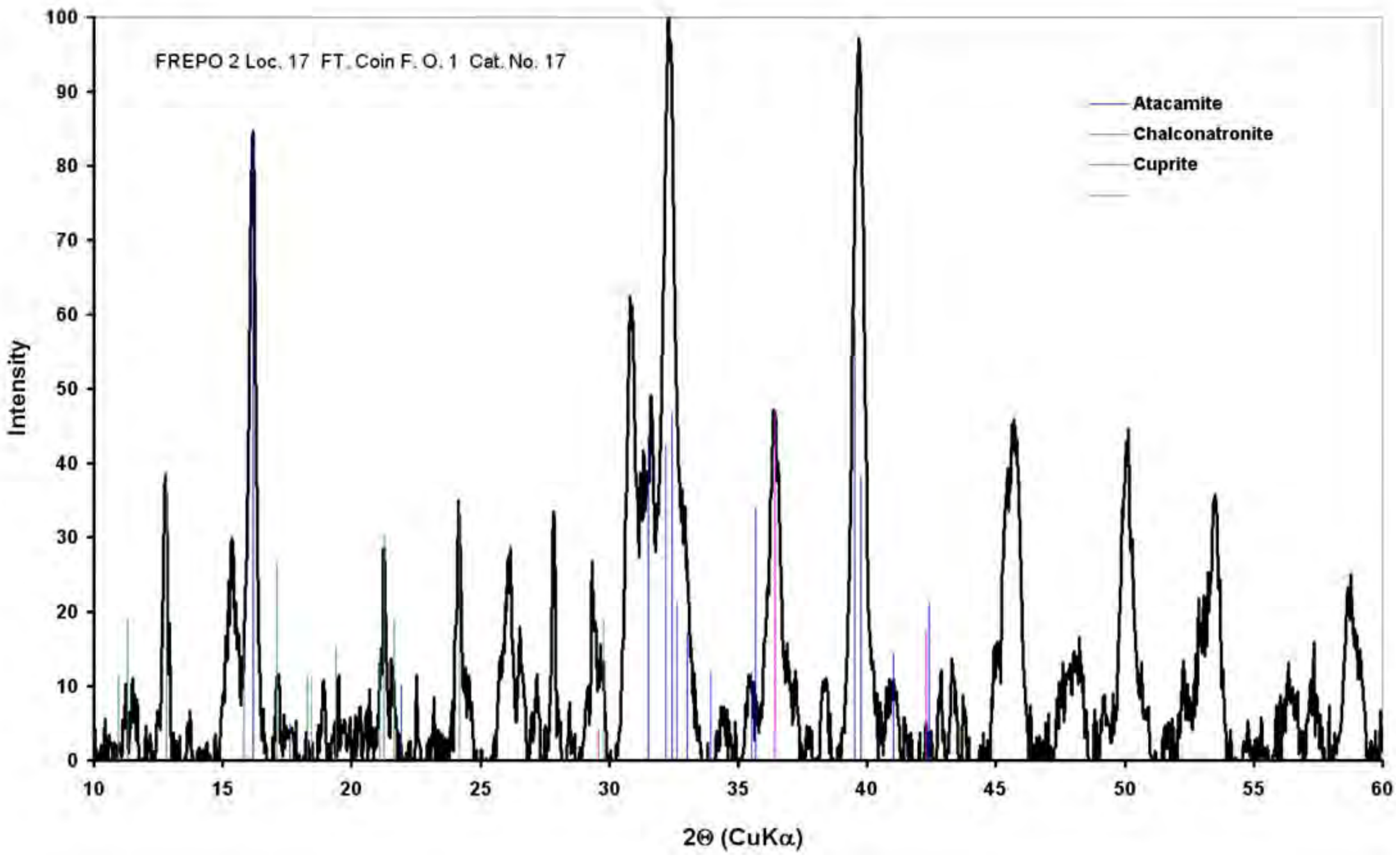



**Figure 30: X-ray diffractogram of green (atacamite) and blueish (chalconatronite) oxidation products on copper coin (FREP 02 Loc. 17 F.O. 1 CAT 17)**

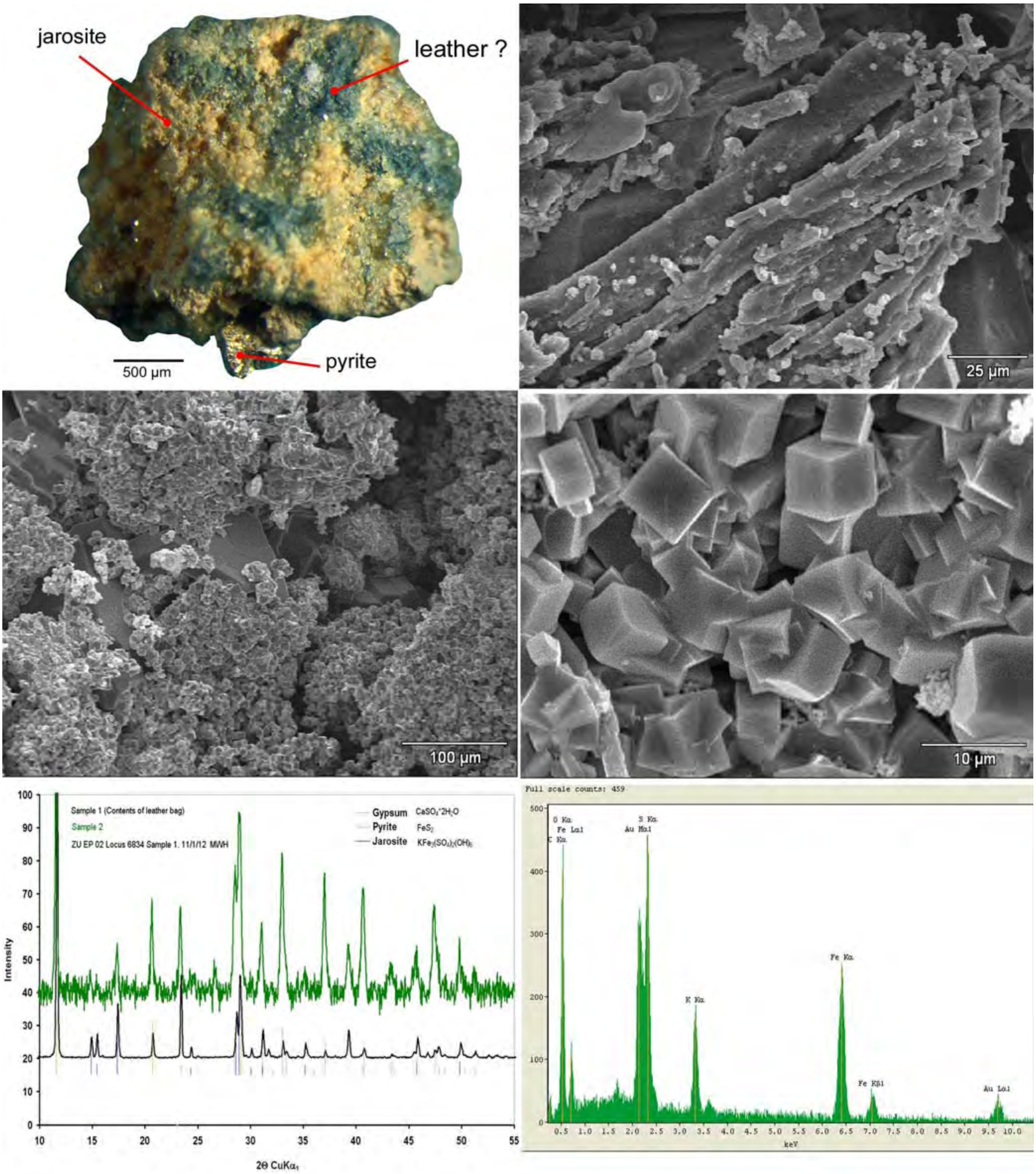



**Figure 31: Samples 1 + 2 ZU EL 02 Locus 6834 (Contents of a leather bag)**
**Top left: Sample 1 (yellow earth and remnants of leather (?) (dark patches of the sample). Top right: SEM photograph of dark patches with fibrous structure. Middle left: Aggregated jarosite crystals and gypsum. Middle right: Rhombohedral jarosite crystals. Bottom left: X-ray diffractograms of samples 1 and 2. Bottom right: EDX diagram of jarosite (Au coated).**

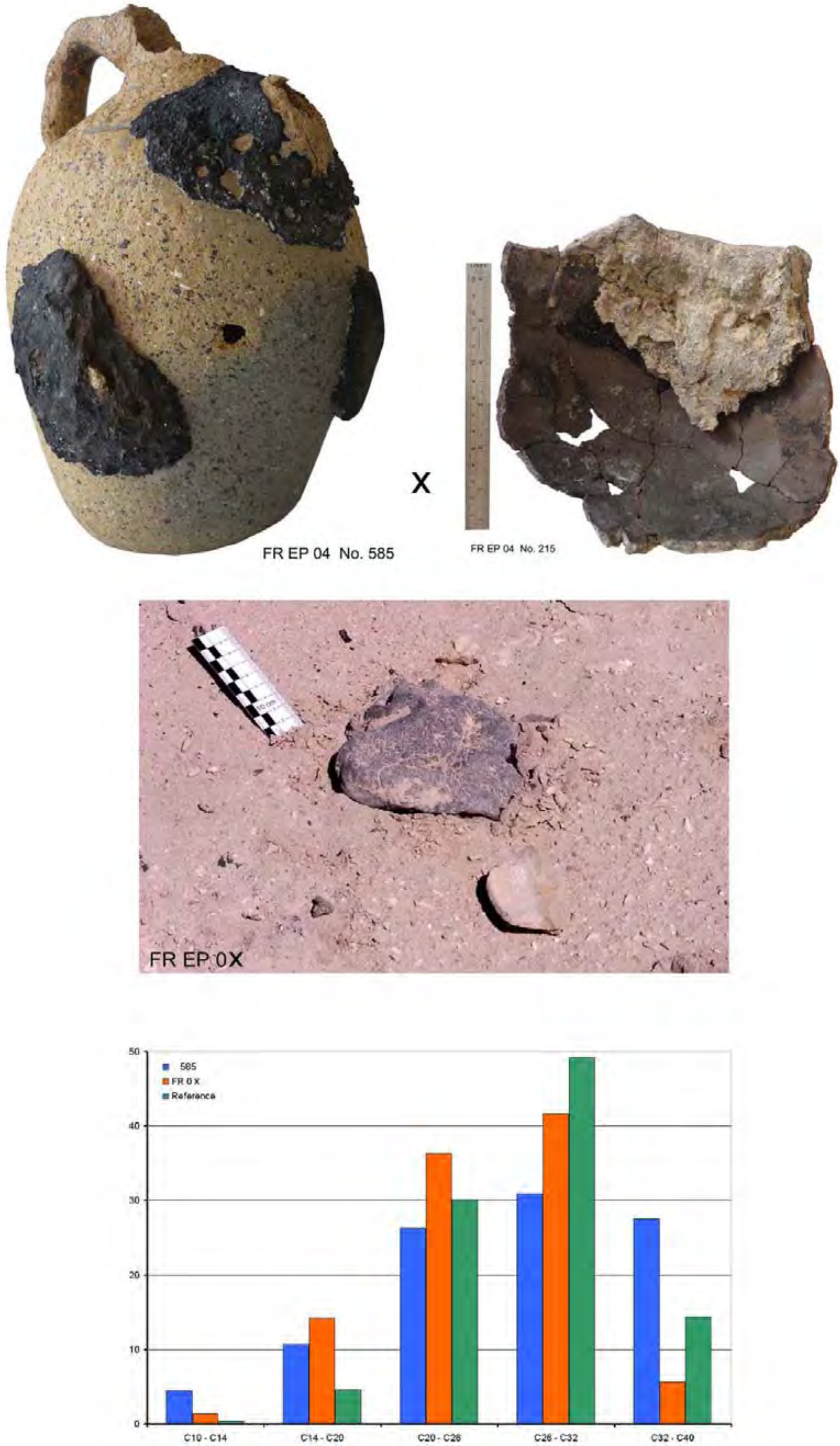



**Figure 32: Top: Different finds of bitumen from Freya.**
**Bottom: Distribution of aliphatic hydrocarbons**

In the collection of finds are vessels and vessel fragments which are partly coated with bitumen (**figure 32**). Parts of the Al Zubarah city area are littered with lumps of bitumen that were washed ashore in the wake of the Gulf War oil spill. Superficially looked at there is little difference in the appearance of archaeological bitumen and recent bitumen from the oil spill. Three archaeological bitumen samples from Freya (FR EP 04 585, FR EP 04 215, FR 0x) and a piece of recent bitumen (REF) from a spoil heap in the vicinity of Al Zubarah EP 04 were analysed by gas chromatography with respect to aliphatic (AH) and polycyclic aromatic hydrocarbons (PAH). It was expected that recent bitumen contains distinctly more and lighter AH and PAH than archaeological = old bitumen. However, as the results presented in **table 12** prove this was not the case: the fractions of lighter AH (C10 – C20) and the total amount of PAH were both higher in the archaeological samples. Obviously, the general idea that archaeological and recent bitumen could easily be distinguished by chemical analysis is too simple because it assumed that the starting material had the same or at least a very similar composition before the onset of degradation and that the degradation process took place under similar conditions.

**Table 12: Aliphatic and polycyclic aromatic hydrocarbon contents in archaeological and recent bitumen samples**

| Aliphatic hydrocarbons | Sample | | | |
|---|---|---|---|---|
| | 585 | 215 | FR 0x | REF |
| C10 - C14 | 4,5 | - | 1,36 | 0,40 |
| C14 - C20 | 10,7 | - | 14,21 | 4,60 |
| C20 - C26 | 26,3 | - | 36,36 | 30,15 |
| **C26 - C32** | 30,9 | - | 41,66 | 49,21 |
| C32 - C40 | 27,6 | - | 5,67 | 14,39 |
| C10 - C40 | 100,0 | - | 99,26 | 98,75 |
| > C40 | 0,0 | - | 0,74 | 1,25 |
| Total | 100,0 | - | 100,00 | 100,00 |
| **Polycyclic aromatic hydrocarbons** | | | | |
| Naphthalene | < 0,5 | 0,28 | 0,34 | < 0,05 |
| Acenaphthylene | < 0,5 | < 0,5 | < 0,05 | < 0,05 |
| Acenaphthene | 1,43 | 1,07 | < 0,05 | < 0,05 |
| Fluorene | < 0,5 | < 0,5 | < 0,05 | < 0,05 |
| Phenanthrene | 1,10 | < 0,5 | 0,69 | < 0,05 |
| Anthracene | < 0,5 | 0,03 | < 0,05 | < 0,05 |
| Fluoranthen | 0,90 | 0,24 | < 0,05 | < 0,05 |
| Pyrene | 0,71 | 0,21 | < 0,05 | < 0,05 |
| Benz(a)anthracen | 0,76 | 0,55 | < 0,05 | 0,61 |
| Chrysen | 1,67 | 0,31 | 0,26 | < 0,05 |
| Benzo(b)fluoranthene | < 0,5 | < 0,5 | < 0,05 | < 0,05 |
| Benzo(k)fluoranthene | < 0,5 | < 0,5 | 0,54 | < 0,05 |
| Benzo(a)pyrene | 0,67 | < 0,5 | 0,23 | < 0,05 |
| Indeno(1,2,3-cd)pyrene | < 0,5 | < 0,5 | < 0,05 | < 0,05 |
| Dibenz(a,h)anthracene | < 0,5 | < 0,5 | < 0,05 | < 0,05 |
| Benzo(g,h,i)perylene | < 0,5 | < 0,5 | < 0,05 | 0,53 |
| **Sum PAH** | **7,24** | **2,69** | **2,06** | **1,14** |

## 7. Cooperation with Materials Technology Unit of Qatar University

A link to the Materials Technology Unit of Qatar University has been established. The managing partner on the MTU side is Dr. Mariam A. Al-Maadeed, Head of the Materials Technology Unit, Office of Research. They can assist us with the testing of physical parameters of mortars and the acquisition of appropriate binding materials. There is also a direct cooperation between Dr. Al-Maadeed and the author in the publication of chemical data of pottery sherds from the excavation sites Halat Aobeer and Hazem Al-Jasrah, Qatar..

## 8. Outlook

### 8.1 Documentation of changes in the state of walls as a function of time

The photographic documentation of walls in different states of preservation and geographical orientation over time is a very effective method to get an idea about the rates and mechanisms of decay. **Figures 33 and 34** show that the collapse of wall plaster at different sections of wall c in room 5 depends very much on the state of the wall behind the plaster. If the substrate is no longer consolidated and if there is no more bonding between wall and plaster then there exists a state of metastable to instable equilibrium and the plaster may drop any moment. **Figure 35** demonstrates that a strongly decayed wall can persist in this state for a considerable time.


**Figure 33: Loss of wall plaster at wall c, room 005, South Field**


**Figure 34: Loss of wall plaster at wall c, room 005, South Field**


**Figure 35: Loss of wall plaster at wall c, room 006, South Field**

## 8.2 Consolidation of gypsum wall plaster

The wall plaster plays an important role as sacrificial layer in order to preserve the wall structure behind it. The decay of a wall will always begin with the decay and collapse of the wall plaster. Therefore the consolidation of existing wall plaster which is predominantly a gypsum wall plaster and the renewal of plaster where it has been lost is of utmost importance for the preservation of the wall structures.

To keep the architecture of Al Zubarah city as authentic as possible it is necessary to conserve as much of the original gypsum wall plaster as possible. Basically, there are three states to be considered and handled:

1. The plaster has no or only minor damages (detachment of gypsum flakes) and is well bonded to the wall (stable state).

2. The plaster has a more or less strongly eroded surface, exhibits deep fractures and small holes, but still preserves a weak bonding to the wall (metastable state).

3. The plaster is in a ruined state, broken into several, more or less coherent pieces, some of which are missing while the rest are largely detached from the wall (instable state). In this case not only the plaster is in ruined state but also the wall or what is left of it.

The decision whether state 2 or state 3 is present cannot be made by visual inspection alone. In order to find out to what degree the plaster is detached from the wall careful percussion tests should be made. The result of the evaluation should be documented in a map or photograph and the conserving strategy planned accordingly.

The first or stable state requires little or no attention at all. If necessary a surface consolidation with either Xilan® or acrylic dispersion will be sufficient. Unfortunately this state is rather the exception and not the rule.

The second or metastable state can be mended by filling the cracks and holes and closing possible gaps between the plaster and the wall at the margins. If possible this repair work should be carried out with anhydrite mortar. If this material is not available a lime/natural hydraulic lime mortar will also do. **Mortars containing OPC should by no means be used for this work**. A surface consolidation may finish the job.

The third stage is a real challenge to any conservator. Before the work starts it must be decided if it is really worth the effort to preserve the much dilapidated plaster or if the effect of a wall with a seemingly authentic surface can be achieved by less elaborate means. If the decision is made in favour of restoration/conservation the first step will be the careful detachment of the plaster from the ruined wall. The repair of the wall, especially the creation of a consolidated surface is the second step. After that the plaster pieces can be fixed to the wall again, preferably with anhydrite mortar. Cracks and holes are closed with mortar. This elaborate restoration work will most probably be restricted to walls with decorated plaster while less valuable plasters can be taken off and replaced by new plaster prepared in the old fashion with burnt gypsum.

## 8.3 Visit to comparable excavation projects in the Gulf States

An important thesis as far as the work at Al Zubarah is concerned has been brought to the attention of the author of this report by Prof. Dr. Alan Walmsley. It demonstrates that the same questions and problems we are facing at Al Zubarah have been dealt with in at least one other Gulf State.


ARCHAELOLGICAL SITES IN BAHRAIN

**Summary**

The topic of this thesis is:

(Study of Different Deterioration Factors which Effect on Ruins of some Archaeological Sites in Kingdom of Bahrain with Restoration & Conservation Suggestions. Case Study: Archaeological Ruins of Saar Site). The thesis contains five parts, each part divided into chapters, as follows:

**Part 1**

**Archaeological and Geological study of Bahrain, with focusing on Saar Archaeological Site**

Part one contains three chapters:

**Chapter 1: Historical and Archaeological background of Bahrain**

In the beginning, this chapter described the location of Bahrain islands which is an archipelago located in the middle of Arabian Gulf. The biggest island of this archipelago is Bahrain the mother island .

Then, it gave a brief study about the main characters of different places of Bahrain islands.

This chapter also dealt with Bahrain s history from the stones ages until the Islamic era as follows:

- Stone Ages
- Dilmun Period
- Taylos Period
- Islamic Era

In the end, chapter one gave a brief study about some archaeological sites in Bahrain from different periods.

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**Chapter 2: The Ancient Techniques and Building Materials used in Bahrain:**

This chapter dealt with ancient building materials used in Bahrain in the ancient eras.

The ancient masonry in Bahrain depends mainly on using stones as the major building material with using different types of mortars (gypsum - lime - water conduit sediments) as bonding materials between stones in the walls.

Then, it dealt with the ancient construction techniques in Bahrain.

**Chapter 3: Geoarcheological Study of Saar Archaeological Site:**

In the beginning, it gave a general geological description of Bahrain with focusing on the geological characters of Saar Archaeological Site.

Then, it studied the history and archaeology of Saar Archaeological Site with giving a detailed description for the site before and after excavations / destructions caused by urban development.

The main parts of the site are the settlement and its associated interlock tombs.

The site has a unique character as a well planned city consists of the main road with many allies, and its division into blocks.

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The thesis is written in Arabic with an English summary which is presented here as a poor but readable photocopy. Perusing the directory gives you the feeling that it would be useful to have an English translation of the thesis. And maybe it would be even to better to pay a visit to the site and discuss the topics with the author of the thesis.

**Part 2**

**Deterioration Factors of Archaeological Site Ruins in Bahrain with focusing on Saar Archaeological Site**

This part contains two chapters:

**Chapter 1: Physiochemical Deterioration Factors:**

Physiochemical Deterioration Factors can be divided into:

- Effect of temperature degrees on the archaeological ruins in Bahrain. The high temperatures degrees in Bahrain can cause damage to the building materials of these ruins either in the high degrees or during continual daily and seasonal changes in temperatures.
- Effect of Humidity : water in its different kinds (humidity, sea water vapor, rain water, condensation water and ground water) regard as a common factor in deterioration due to its cooperation with other factors.
- Effect of winds through either accumulating sands beside the archaeological ruins or removing sands from the sandy burial mounds which therefore leads to expose tombs to the weathering factors. Winds also affect on ruins through abrasion their surfaces.
- Effect of Salts: this point dealt with the salts sources, salt kinds and crystallization types of salts. Then, it dealt with the effect of salts on the ancient porous building materials.
- Effect of gaseous pollutants such as, Sulfur dioxides, Carbon dioxides, Nitrogen compounds and aerosols particles.

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**Chapter 2: Biological and Man-made Deterioration Factors:**

In the beginning, this chapter dealt with the physical and chemical effects of the different biological deterioration factors such as; animals, birds, insects and plants. Then, it dealt with the effect of microbiological factors such as; bacteria, fungi, lichens and algae.

In the end, it dealt with effect of man-made deterioration which regard as the most dangerous factor threaten the archaeological heritage in Bahrain.

The man-made deterioration factor affect on archaeological sites in Bahrain through various ways as follows:

- Inappropriate restorations
- Archaeological excavations as a damaging factor
- Effect of mass tourism
- Impact of development, bad behaviors of local community and vandalisms

**Part 3**

**Restoration and Conservation of Archaeological Site Ruins**

This part was divided into three chapters depending on the type of the intervention for preserving archaeological sites.

**Chapter 1: Direct Intervention / Conservation of archaeological site Ruins:**

In the beginning, it dealt with methods of conservation before excavations such as documentation, fencing.etc.

Then, it dealt with the methods of conservation during and after excavations as follows:

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- Cleaning the site from garbage and accumulated sands beside walls. Then, cleaning the surfaces of ruins from dusts and salts by using mechanical and chemical methods.
- Mechanical and chemical consolidation of ruins.
- Completion and reconstruction of archaeological ruins.
- Solutions for the problem of ground water.
- Long-term conservation of the site, such as; backfilling, using protective shelters, drainage systems, walls capping, removing of dangerous plants, protection from the bad effect of winds (forestation) and protection of sites boundaries.
- Monitoring

**Chapter 2: Indirect Intervention / Conservation of Archaeological site Ruins:**

This chapter dealt with the methods of preserving archaeological sites without direct dealing with their components relying on raising the public awareness of the importance of these archaeological sites. This goal can be achieved thro encouraging and activating the roles of various members/ bodies in the local community, such as; the role of family, media, education, security, planning and tourism bodies.

**Chapter 3: Preparation of Archaeological sites for Visitors:**

In the beginning, this chapter gave some principles and rules of development and preparation of archaeological sites for visitors. Then, it dealt with the methods of the implementation which were divided as follows:

- Site infrastructures, such as; roads leading to the site, car parking, the gate and tickets office, visiting trails, cafeteria, gift shops and litter bins.
- Site presentation and interpretation methods, such as; visitors center, collections museum, open-air museum, interpretive panels, booklets and visitors guide.

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**Part 4**

**Scientific Analysis and Laboratory Examinations for educing the appropriate restoration materials**

This part contains two chapters:

**Chapter 1: methods of scientific Analysis**

This chapter dealt with the various analysis methods used to study the components of some old building materials (stones- mortars- plasters) from Saar Archaeological Site. Samples have been studied by using X- ray diffraction, chemical analysis and petrography study to find out their components, and then choose the appropriate restoration materials.

The results revealed that the stones are Dolostone, the mortars and plasters are mainly from gypsum with minor components from lime and sands.

Some mechanical and physical tests carried out on two samples of stones from Saar Archaeological Site.

The chapter also studied some biodeterioration samples taken from stones from Saar Archaeological Site.

**Chapter 2: Laboratory Examinations**

Numbers of new mortar and plaster samples with different proportions were prepared in the lab and they tested to find out their mechanical and physical properties.

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By all means, it would make sense to visit similar sites in any of the Gulf States in order to study how other groups of conservators, engineers, and scientists have tackled the problems. I know that we are a good team but that does include the ability to learn from other people, too..

This chapter also studied some consolidants applied on stones and plasters and then examined them with SEM to find out their results.

**Part 5**

**Proposal Plan for Conservation and Development of Saar Archaeological Site Ruins**

This part contains two chapters:

**Chapter 1: Proposal Plan for Conservation:**

This chapter proposed steps of implementation of the conservation plan for Saar Archaeological Site.

The conservation plan of Saar Archaeological Site includes:

- Accurate documentation of the archaeological ruins in the site.
- Removing all garbage, accumulated sand besides walls, removing dangerous plants, and cleaning surfaces of walls from salts and biodeterioration products.
- Refilling/repointing of loosing mortars in the walls.
- Completion and reconstruction of some damaged walls.
- Setting unsettled / swelling walls.
- Capping tops of walls.
- Repair and fix damaged wall plasters.
- Removing inappropriate interventions in the site.
- Buying the site and protect its boundaries.
- Forestation of opened sandy area surrounding site.

This chapter also dealt with the methods of raising the public awareness of the local community in Bahrain.

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**Chapter 2: Proposal Plan of Development and preparation the site for visitors:**

This chapter dealt with importance of Saar Archaeological Site which qualified it to be prepared for public to visit.

Then, it gave approposal plan contains steps of preparation the site for visitors.


صورة رقم (١٤٦)
توضح الموقع المقترح لمركز الزوار مع توضيح مسار الزيارة

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المواقع الأثرية في مملكة البحرين / آركيولوجيا
سلمان أحمد المحاري / مؤلف من البحرين
الطبعة الأولى ، 2009
حقوق الطبع محفوظة

المؤسسة العربية للدراسات والنشر
المركز الرئيسي :
بيروت ، الصنايع ، بناية عيد بن سالم ،
ص.ب :11-5460 ، هاتفاكس : 751438 / 752308 1 00961

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التنفيذ الطباعي : مصطفى قانصو للطباعة والتجارة / بيروت ، لبنان



رقم الإيداع بدائرة المكتبات العامة : د. ع 7381 / 2008
ISBN 987-99958-0-056-7

# APPENDIX 5

# On Mortars

## AT AL ZUBARAH / QATAR

Report by Robert Sobott
Februray 2011

## X-ray diffraction phase analysis of mortar samples from the excavation site at Zubarah, Qatar

In June 2010 several tests with different kinds of mortar were made to consolidate the locally dilapidated wall structures at the Zubarah excavation site. Damaged joints were repointed with hydraulic lime,d anhydrite, and mud mortar and small sections of a collapsed tower structure were bricked up with hydraulic lime mortar. Historic gypsum wall plaster was tentatively consolidated with “nano lime”, a dispersion of nano-sized portlandite particles in ethanol. In December 2010 the test sites were revisited and the performance of the different mortars judged by appearance and haptic tests. Already at the site it was realized that surprisingly the anhydrite mortar did not much better than the mud mortar while the test areas with the hydraulich lime mortar looked satisfactorily.

In order to put the explanations for failure or success on a sound data basis samples were taken for laboratory investigations which comprised the X-ray diffraction (XRD) phase analysis, the microscopy of thin sections, and the scanning electron microscopy (SEM).

X-ray diffraction analysis was used to identify the qualitative composition of a sample from which conclusions can be drawn with respect to the nature of a mortar ( anhydrité/gypsum or lime/hydraulic lime mortar) and in the case of the mortars applied in June 2010 and sampled in December 2010 how the consolidation reaction had proceeded.

Three different kind of reactions can be differentiated (compounds printed in bold characters can be detetcted by X-ray diffraction, mineral names given in brackets):

**1. Pure lime mortar:** $\mathbf{Ca(OH)_2} + CO_2 \rightarrow \mathbf{CaCO_3} + H_2O$

(portlandite) (calcite)

**2. Hydraulic lime mortar:** $2\mathbf{Ca_2SiO_4} + 4H_2O \rightarrow \mathbf{Ca(OH)_2} + Ca_3(SiO_3OH)_2{*}2H_2O$

(dicalciumsilicate) $\mathbf{Ca(OH)_2} + CO_2 \rightarrow \mathbf{CaCO_3} + H_2O$

**3. Anhydrite mortar** $\mathbf{CaSO_4} + 2H_2O \rightarrow \mathbf{CaSO_4{*}2H_2O}$

(anhydrite) (gypsum)

In the case of the pure lime and anhydrite mortar the progress of reaction can be easily followed by the disappearance of portlandite or anhydrite and the appearance of calcite and gypsum, respectively. The hydraulic mortar shows two reactions. First, the hydrolysis of calcium silicate phases (C2S, C3S) to form calcium silicate hydrate phases, and, second, the carbonation of portlandite which yields calcite. Unfortunately the calcium silicate hydrate phases are X-ray amorphous and cannot be detected by X-ray diffraction. While the hydrolysis of calcium silicates and the formation of solidified calcium silicate hydrate phases is achieved within hours and days, the carbonation of portlandite and the formation of calcite takes several weeks,and the uncatalyzed re-hydration of anhydrite in the presence of water to form gypsum would require years. Therefore anhydrite mortars contain an accelerating agent which can be an alkaline sulfate or alkaline earth hydroxide.

In order to react completely, the starting materials require an appropriate amount of water or carbon dioxide, respectively. If water is removed from the reaction, either by evaporation and/or capillary suction of porous materials, or if the diffusion of $CO_2$ is hampered/blocked by impermeable barriers then the reactions will be incomplete and the resulting mortars apart from being of poor quality contain remnants of the starting compounds..

A fully reacted anhydrite mortar should contain no more anhydrite and consist entirely of gypsum. Likewise, lime and hydraulic lime mortars should contain no more calcium silicate phases and/or portlandite.

With this general outline in mind the samples compiled in table 1 were investigated by X-ray diffraction and the results listed in table 2 interpreted accordingly.

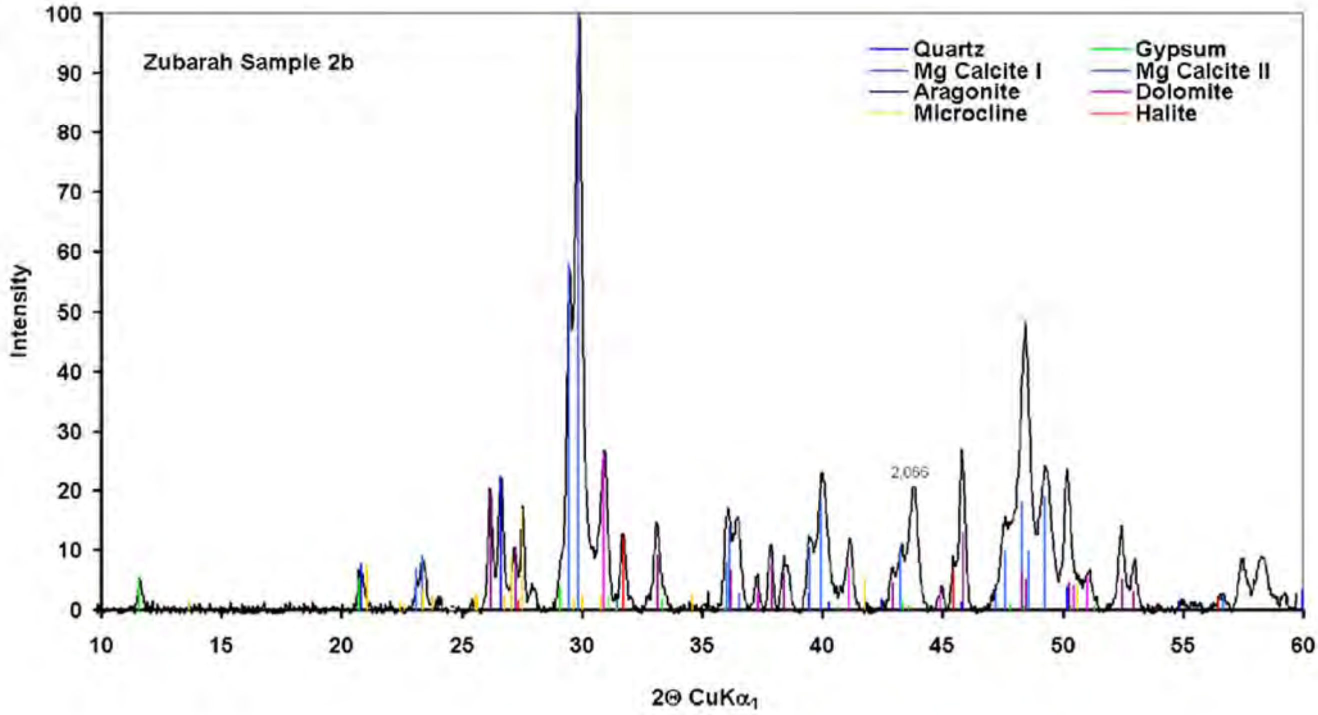
**Table 1: Mortar samples from Zubarah** (sample nos. 2b, II – XIII are consistent with the numbers in the "Documentation of Test Consolidation of Wall Structures, June 2010" by M. Kinzel)

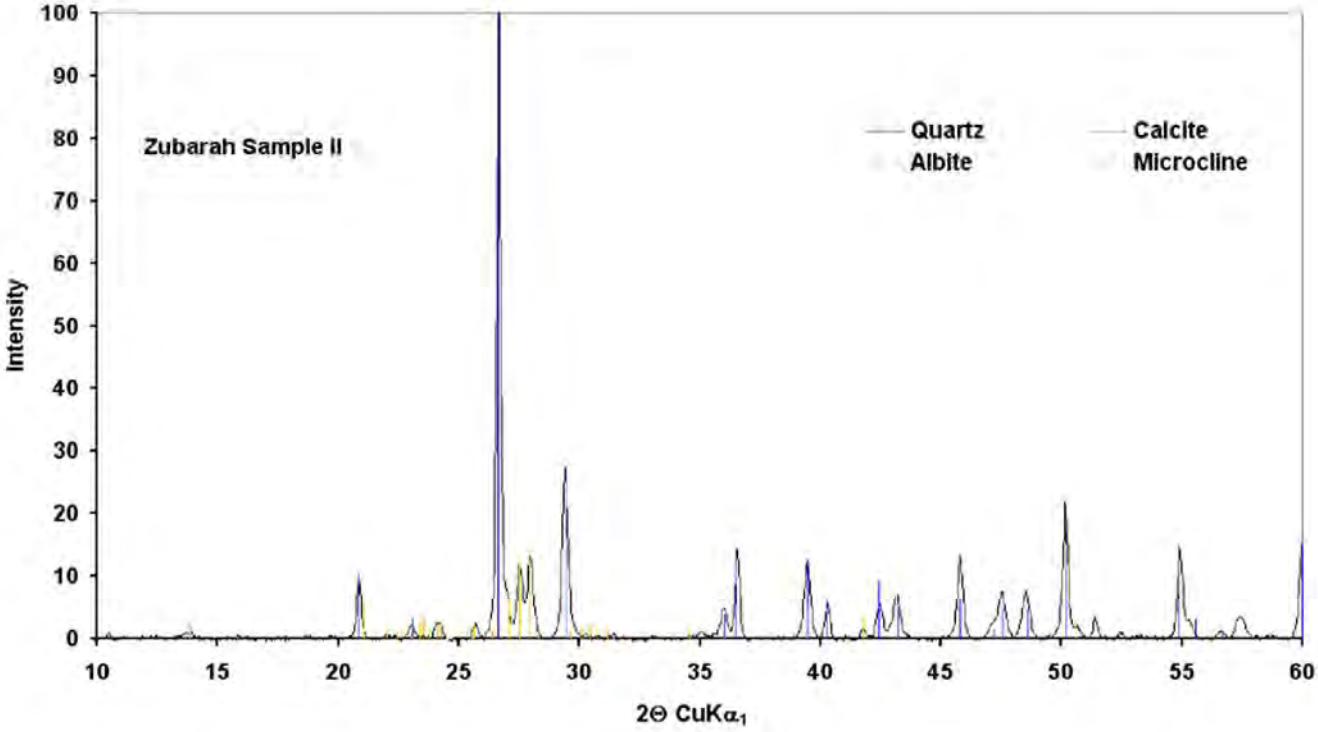
| Sample No. | Locality | Material | Analytical problem |
|---|---|---|---|
| **2b** | wall structure, test field 2b | "nano lime" | reaction products, NaCl contents |
| **II** | Eastern part of tower structure | hydraulic lime mortar with quartz sand 1:3 | reaction products, NaCl contents |
| **IV** | Northern part of tower structure | anhydrite mortar with quartz sand 1:2 | reaction products, NaCl contents |
| **IX** | Western part of tower structure | anhydrite mortar with quartz sand 1:2 | reaction products, NaCl contents |
| **X** | Eastern part of tower structure | anhydrite mortar with quartz/shell sand 1:2 | reaction products, NaCl contents |
| **XI** | Eastern part of tower structure | hydraulic lime mortar with quartz/shell sand 1:3 and 1% tylose | reaction products, NaCl contents |
| **XII** | Southern part of tower structure | hydraulic lime render with quartz sand 1:1 and 1% tylose | reaction products, NaCl contents |
| **XIII** | Western part of tower structure | hydraulic lime render with quartz sand 1:1 and 1% tylose | reaction products, NaCl contents |
| **XIV** | Zubarah Fort | render | composition |
| **XV** | Freyha | historic mortar ? | composition |
| **XVII** | Fort "2" | render | composition |
| **XVIII** | Fort "2" | thin render | composition |
| **XX** | Southfield | render | composition |
| **XXI** | | local anhydrite mortar | composition |

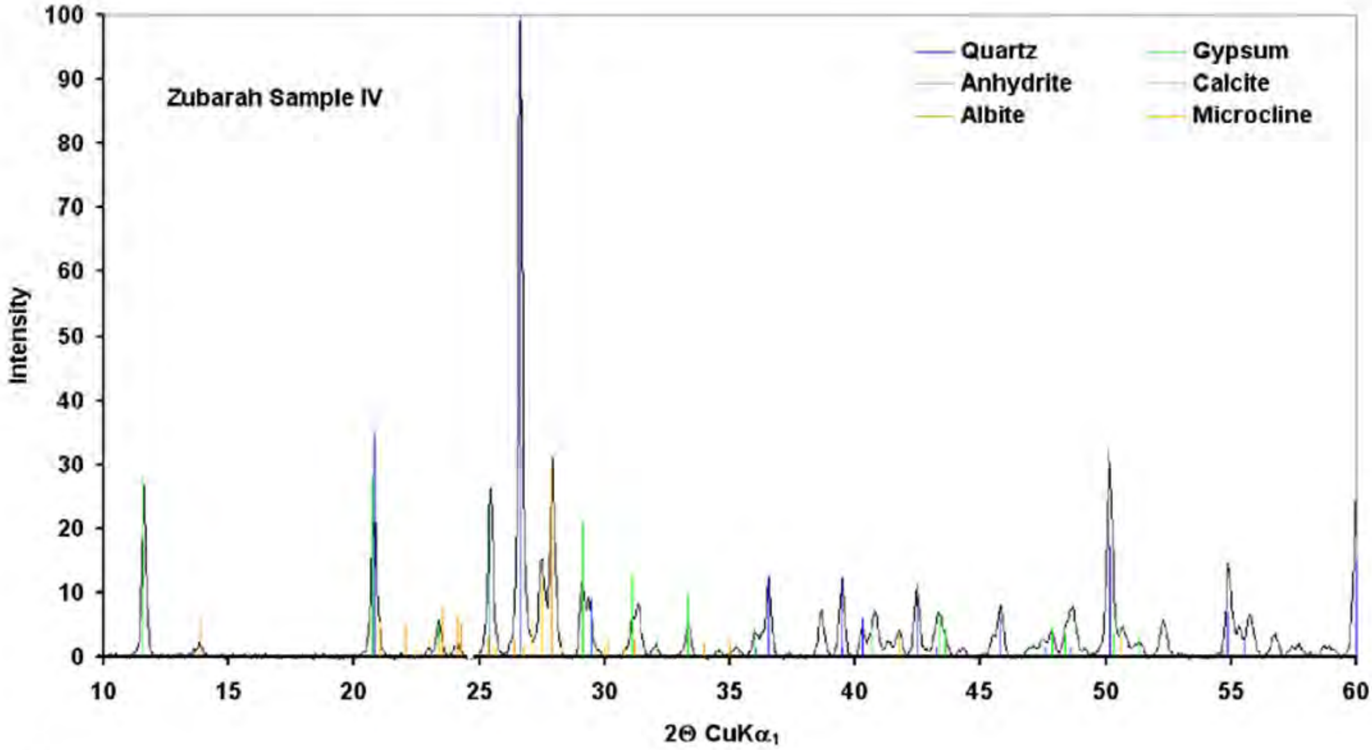
**Table 2: Summary of XRD data for stone and mortar samples**

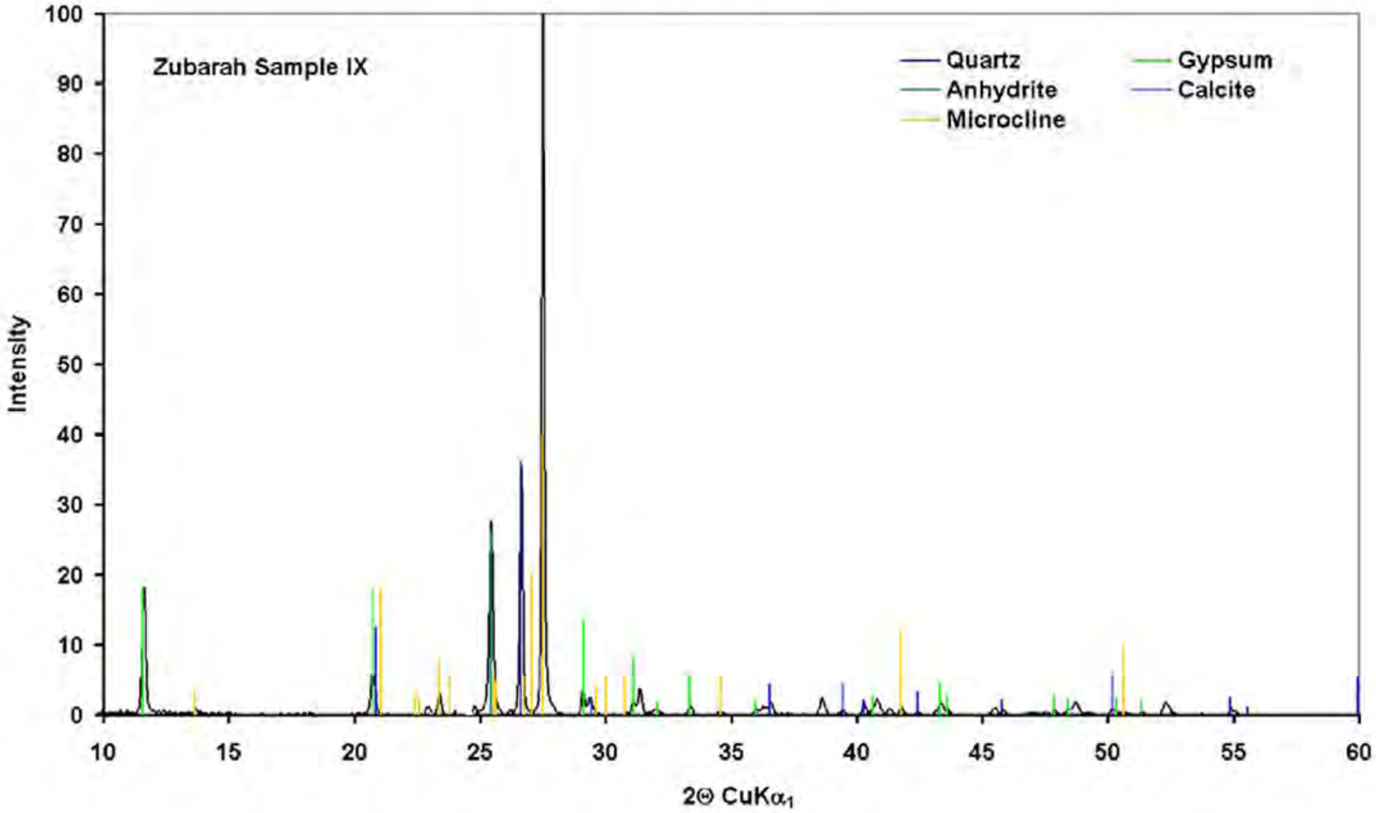
0 phase not detected (< 1.5 mass% or not present) 1 trace to minor component 2 minor to major component 3 major component

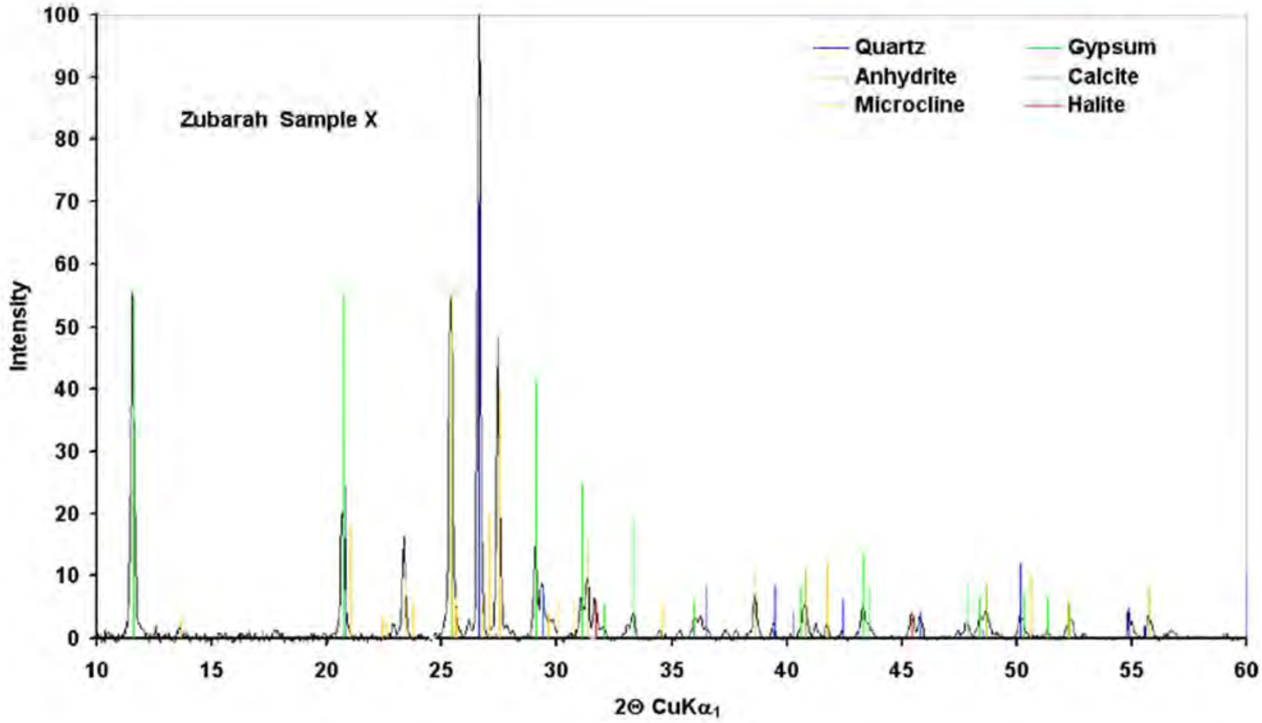
| | Sample | Calcite | Aragonite | Mg calcite I | Mg calcite II | Dolomite | Gypsum | Bassanite | Anhydrite | Halite | Quartz | Plagioclase | K-feldspar | Hydrotalcite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MORTAR | **2b** | 0 | 2 | 3 | 3 | 2 | 1 | 0 | 0 | 2 | 2 | 0 | 2 | 0 |
| | **II** | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 1 | 0 |
| | **IV** | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 3 | 2 | 2 | 0 |
| | **IX** | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 3 | 0 |
| | **X** | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 3 | 0 | 2 | 0 |
| | **XI** | 3 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 3 | 0 | 0 | 0 |
| SAMPLES | **XII** | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 2 | 0 |
| | **XIII** | 2 | 2 | 3 | 0 | 2 | 1 | 0 | 0 | 2 | 2 | 2 | 0 | 0 |
| | **XIV** | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 1 | 2 | 0 |
| | **XV** | 2 | 1 | 0 | 0 | 3 | 2 | 0 | 0 | 1 | 2 | 1 | 1 | 0 |
| | **XVII** | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 1 | 0 |
| | **XVIII** | 3 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 3 | 1 | 1 | 0 |
| | **XX** | 2 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| | **XXI** | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 0 | 0 | 2 |


Zubarah Sample 2b
Quartz
Mg Calcite I
Aragonite
Microcline
Gypsum
Mg Calcite II
Dolomite
Halite
2,066
Intensity
2Θ CuKα1
0
10
20
30
40
50
60
70
80
90
100
10
15
20
25
30
35
40
45
50
55
60

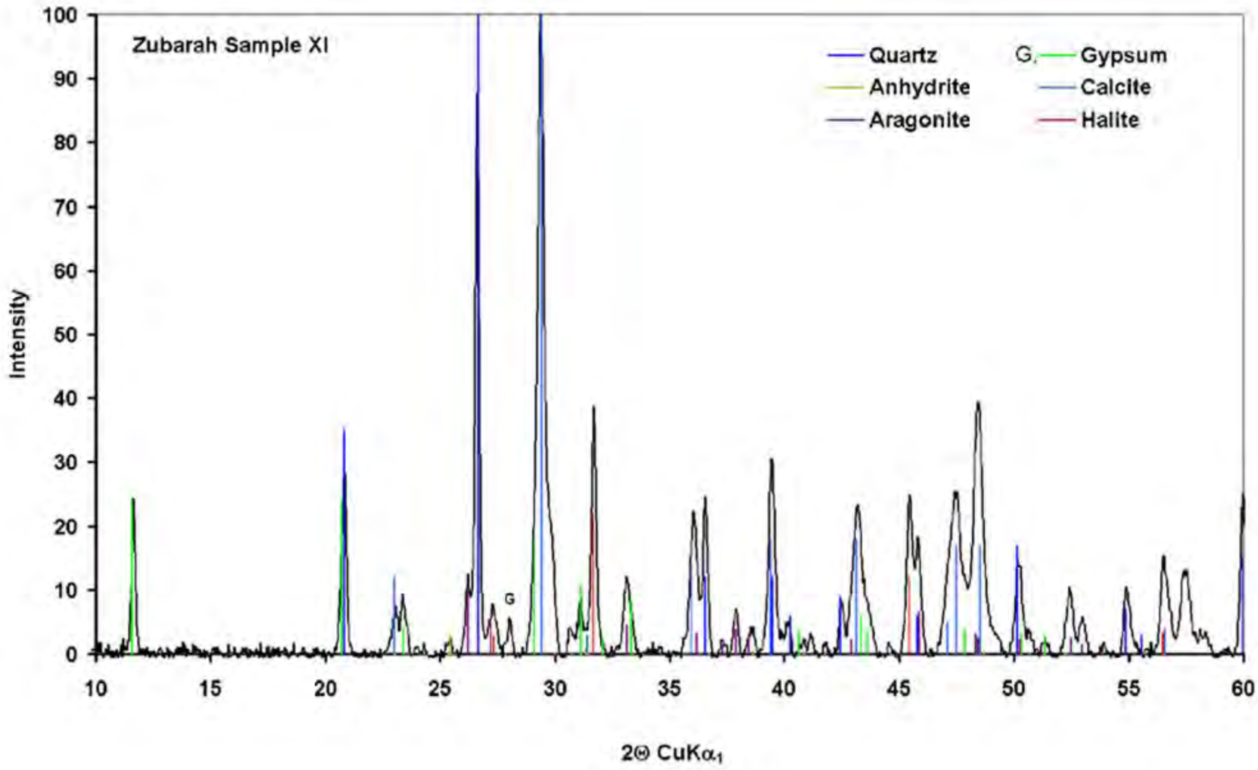

Zubarah Sample II
Quartz
Albite
Calcite
Microcline
Intensity
2Θ CuKα1
0
10
20
30
40
50
60
70
80
90
100
10
15
20
25
30
35
40
45
50
55
60


Zubarah Sample IV
Quartz
Gypsum
Anhydrite
Calcite
Albite
Microcline
Intensity
2Θ CuKα1

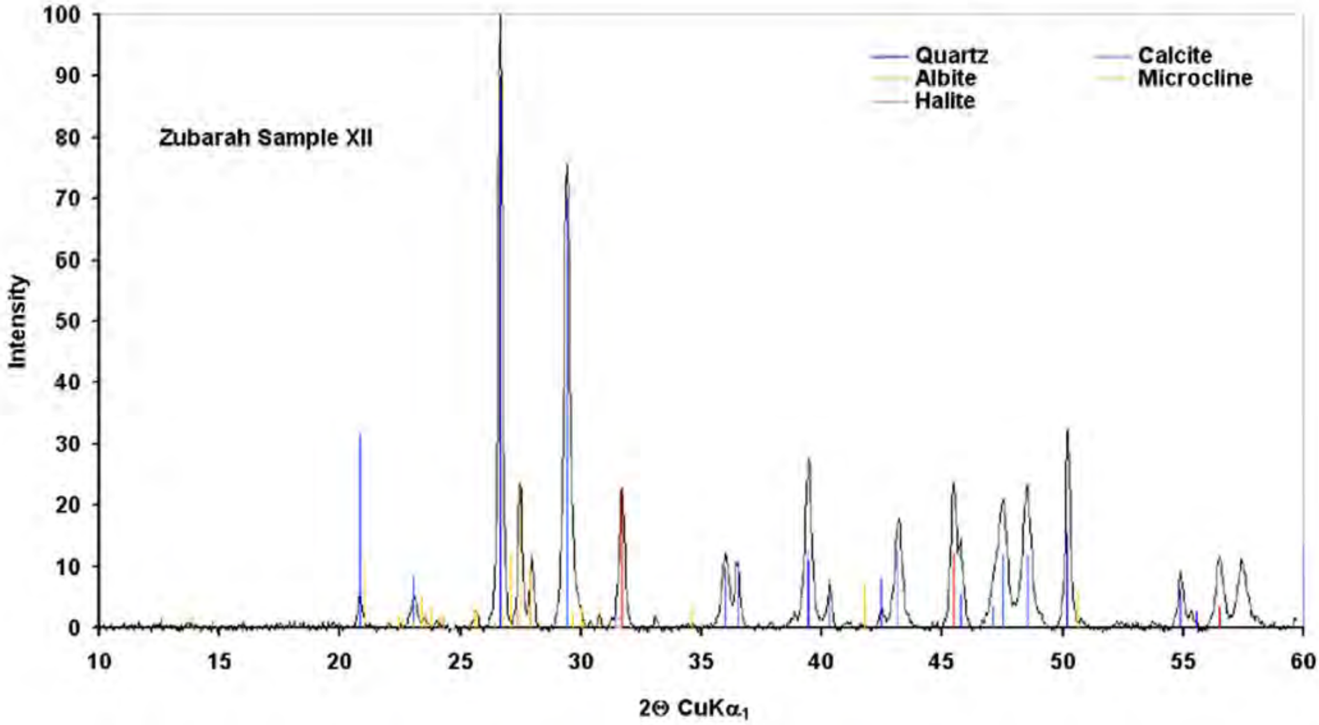

Zubarah Sample IX
Quartz
Gypsum
Anhydrite
Calcite
Microcline
Intensity
2Θ CuKα1

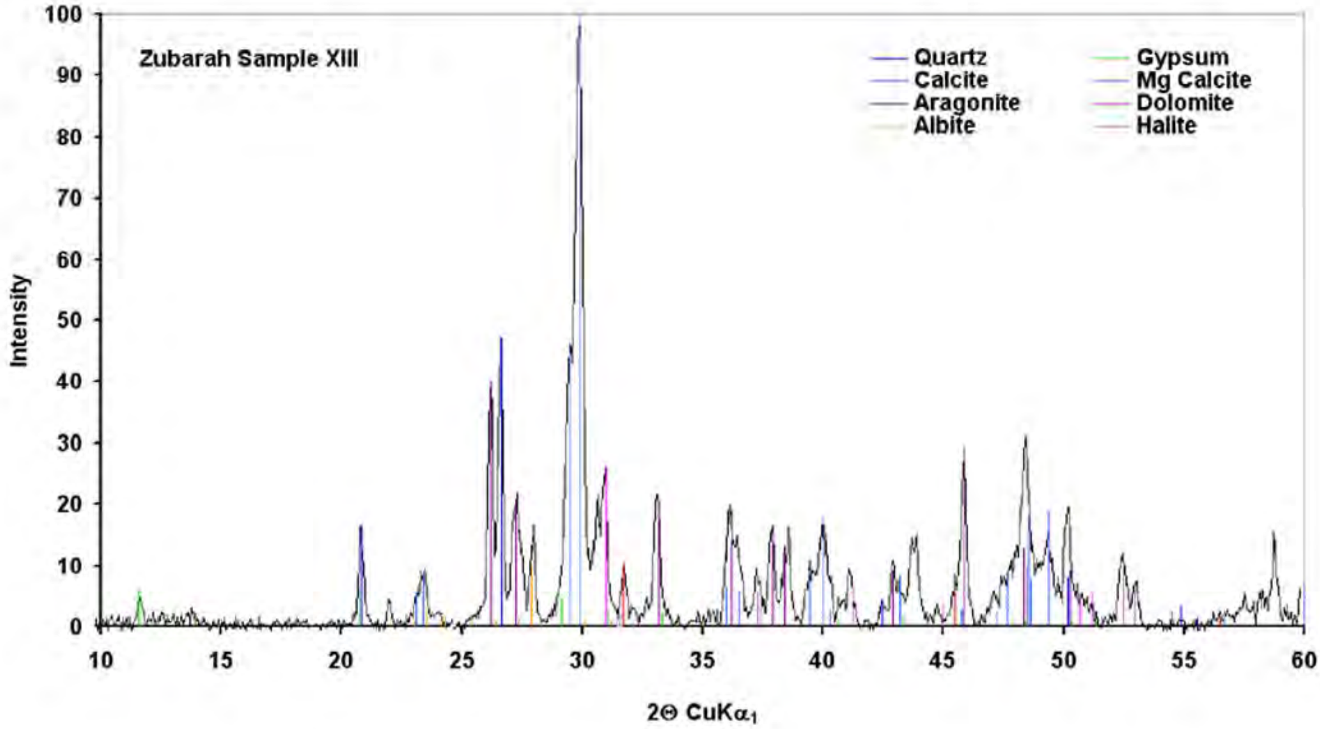


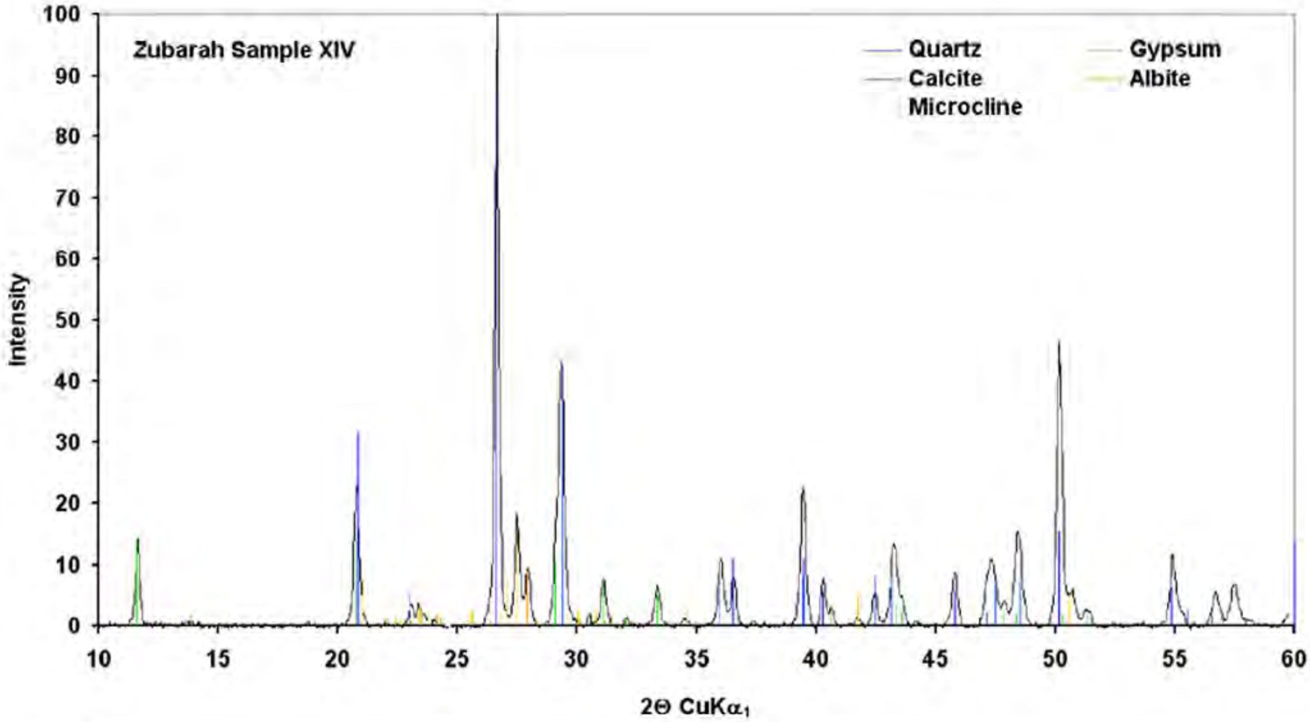
Zubarah Sample X
Quartz
Gypsum
Anhydrite
Calcite
Microcline
Halite
Intensity
2Θ CuKα1

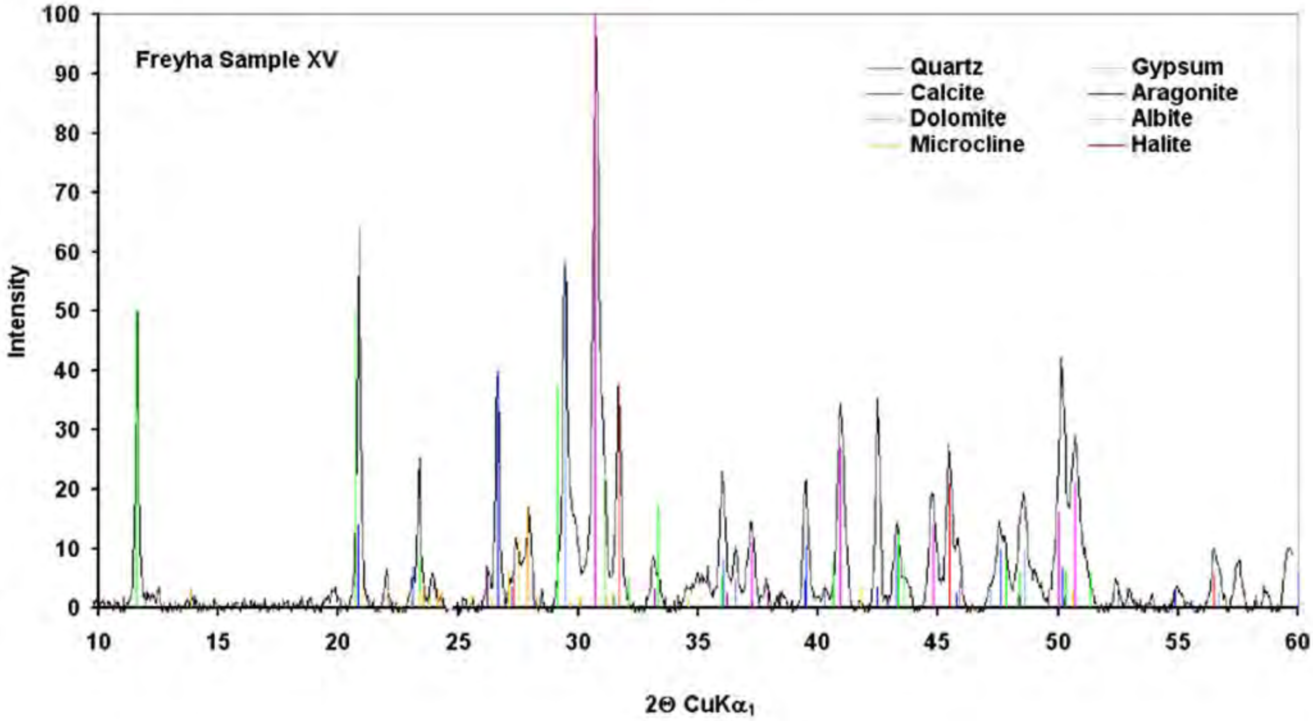



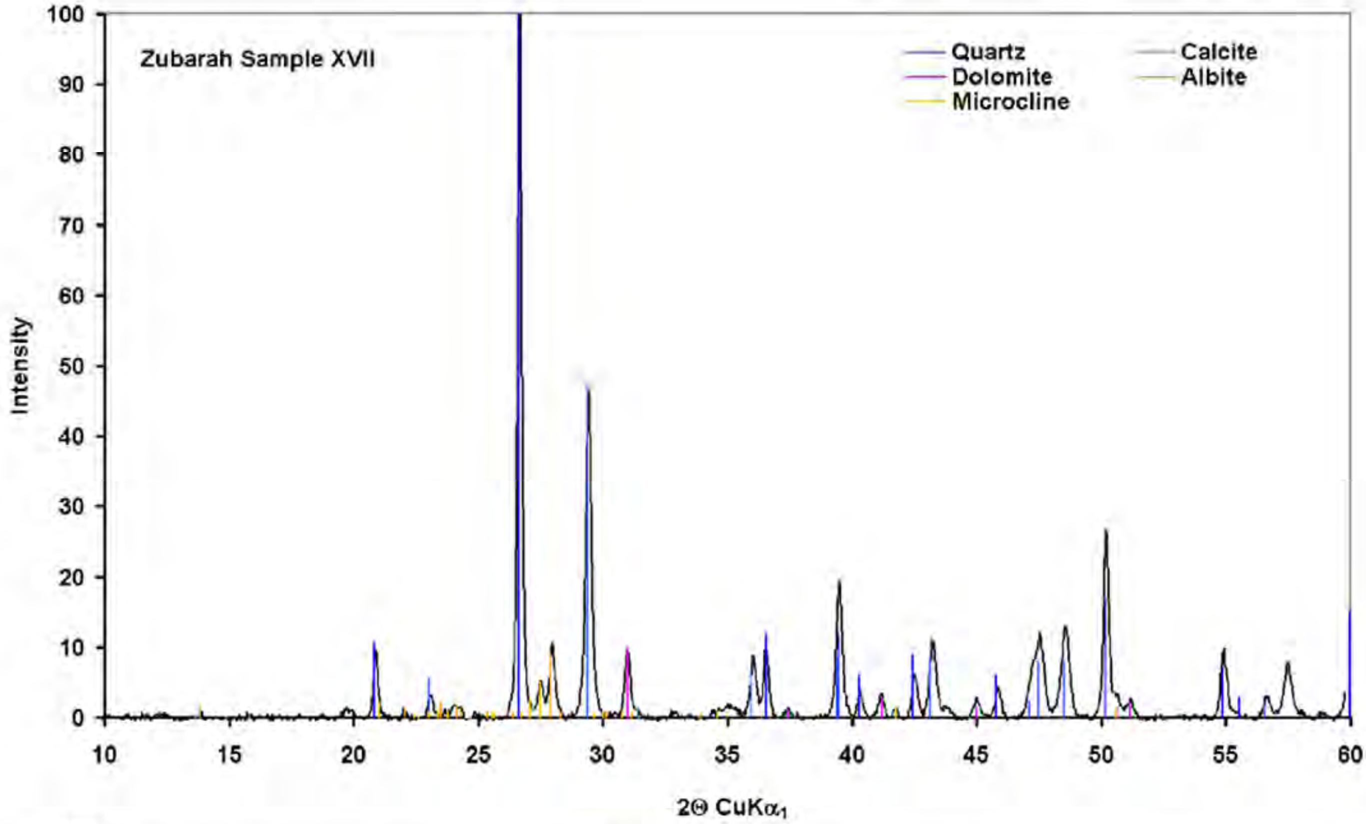
Zubarah Sample XI
Quartz
G, Gypsum
Anhydrite
Calcite
Aragonite
Halite
G
Intensity
2Θ CuKα1

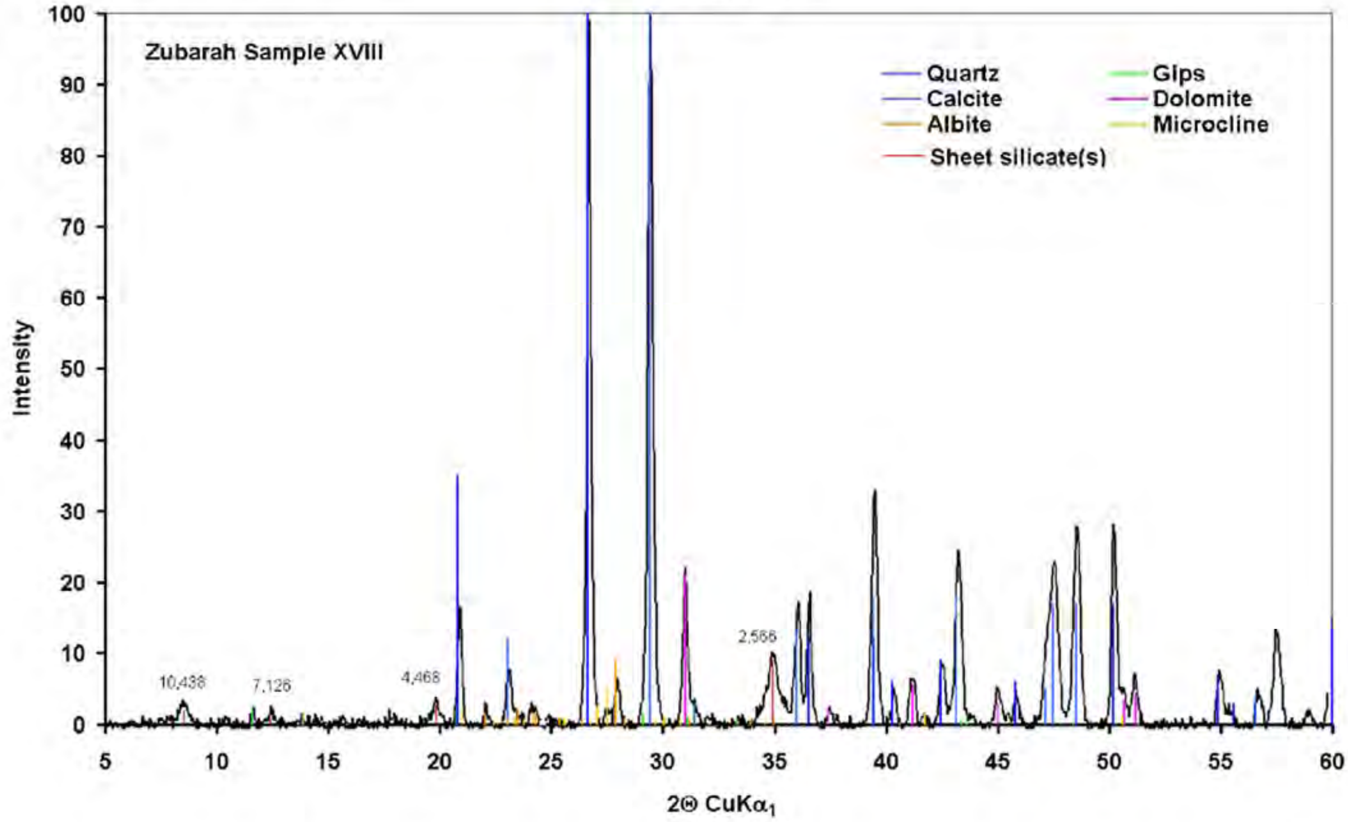

Zubarah Sample XII
Quartz
Albite
Halite
Calcite
Microcline
Intensity
2Θ CuKα1

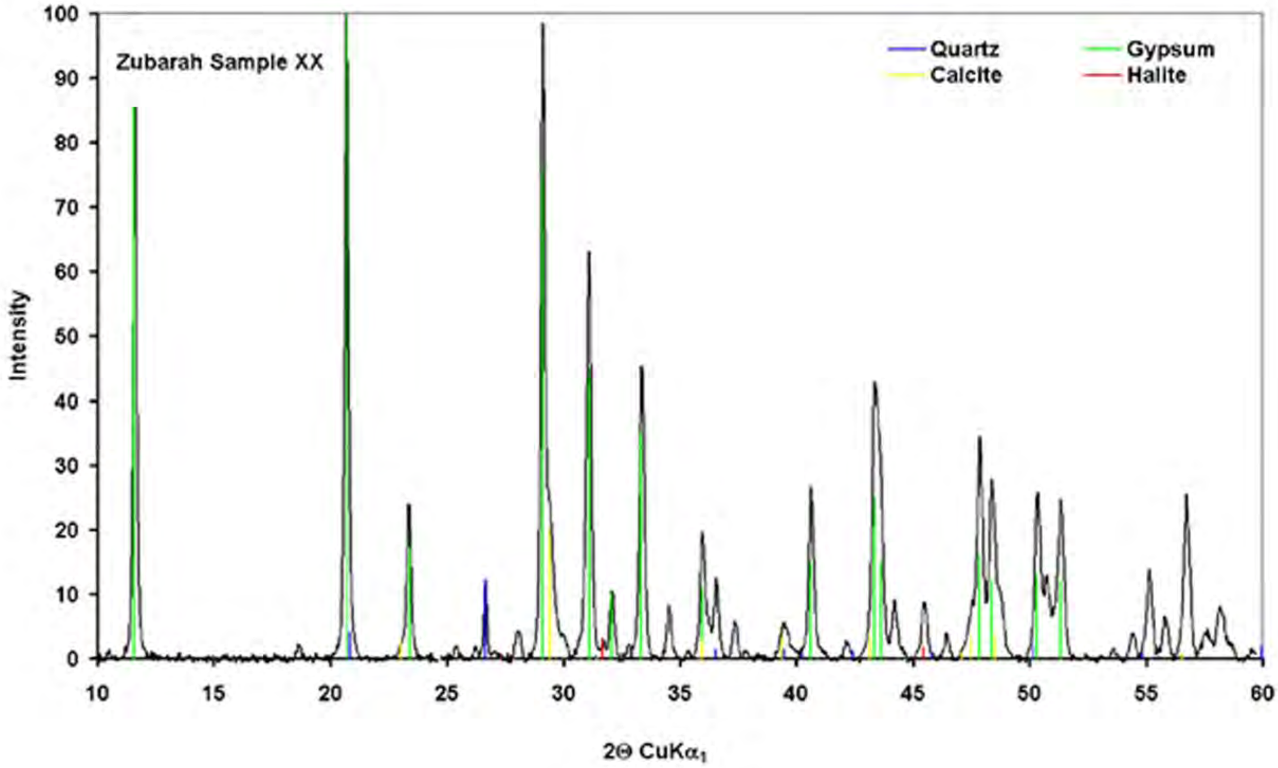

Zubarah Sample XIII
Quartz
Calcite
Aragonite
Albite
Gypsum
Mg Calcite
Dolomite
Halite
Intensity
2Θ CuKα1


Zubarah Sample XIV
Quartz
Calcite
Microcline
Gypsum
Albite
Intensity
2Θ CuKα1

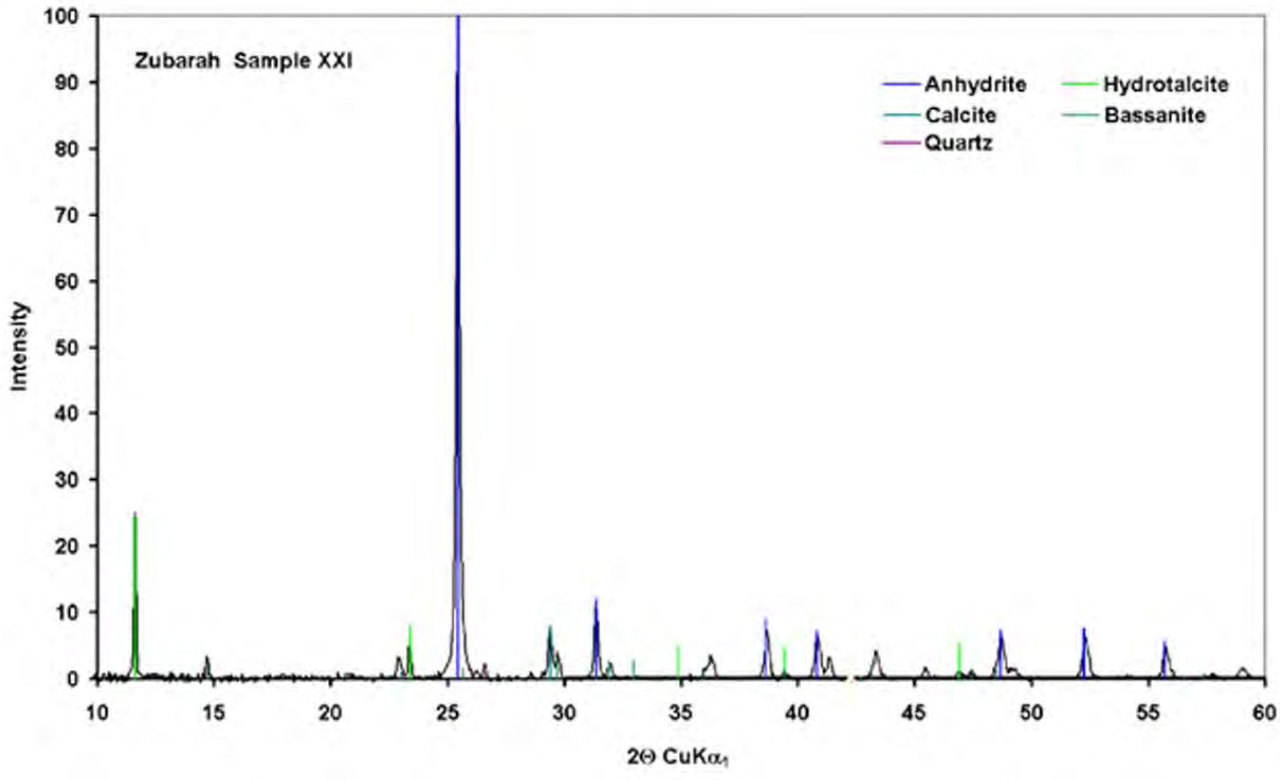

Freyha Sample XV
Quartz
Calcite
Dolomite
Microcline
Gypsum
Aragonite
Albite
Halite
Intensity
2Θ CuKα1


Zubarah Sample XVII
Quartz
Calcite
Dolomite
Albite
Microcline
Intensity
2Θ CuKα1


Zubarah Sample XVIII
Quartz
Gips
Calcite
Dolomite
Albite
Microcline
Sheet silicate(s)
10,438
7,126
4,468
2,566
Intensity
2Θ CuKα1



Zubarah Sample XX
Quartz
Gypsum
Calcite
Halite
Intensity
2Θ CuKα1

Zubarah Sample XXI
Anhydrite
Hydrotalcite
Calcite
Bassanite
Quartz
Intensity
2Θ CuKα1

## APPENDIX 6

# Analyses of Mortar samples

## FROM AL ZUBARAH / QATAR

Report by Robert Sobott
December 2011

## Samples from Al Zubarah  December 2011

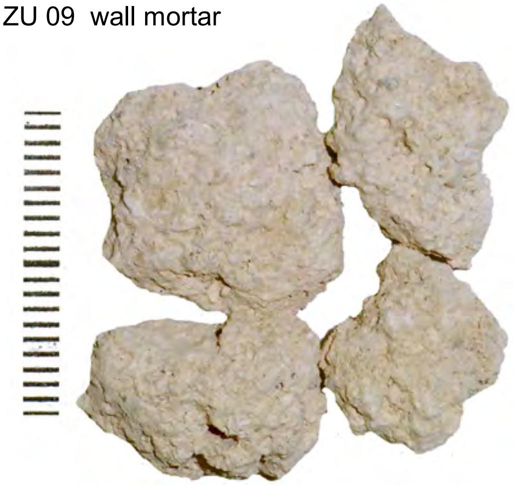
ZU 01
upper layer of gypsum plaster

ZU 04  sample from Moritz

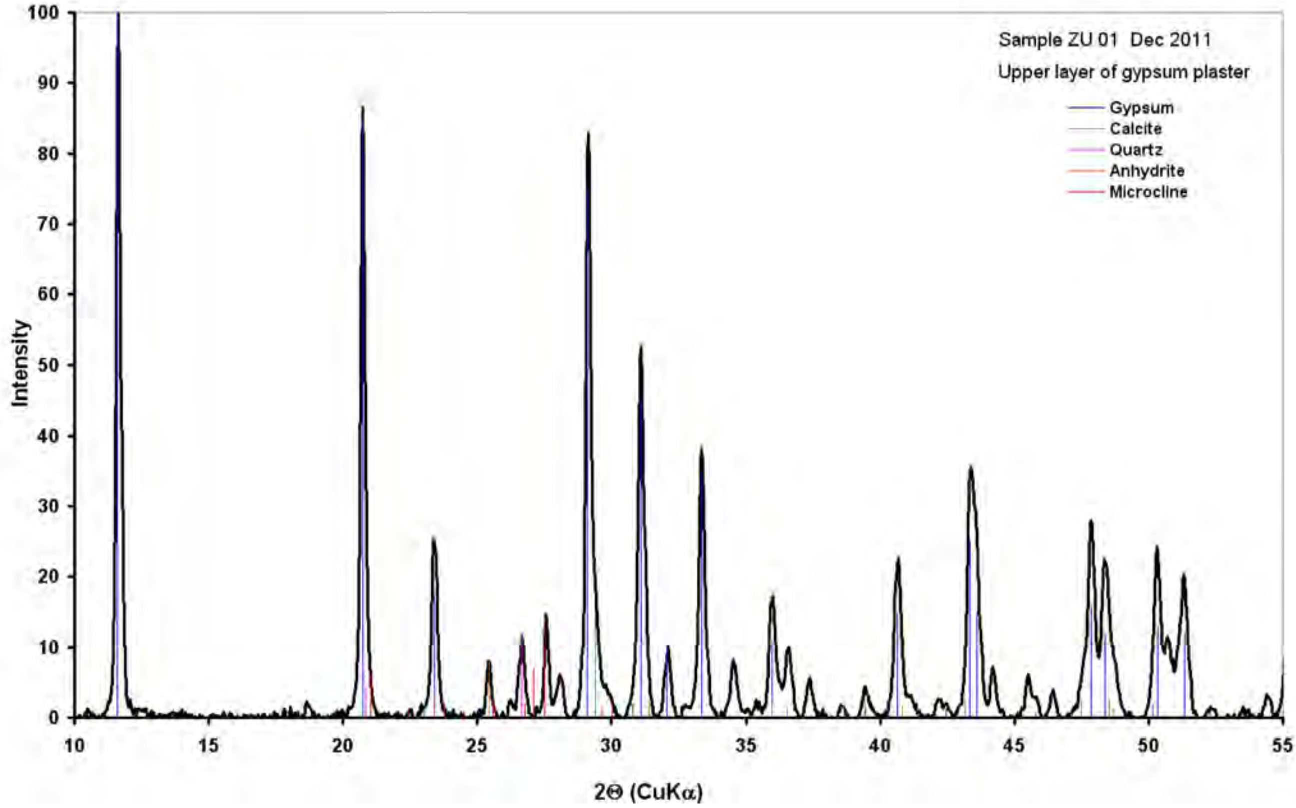
ZU 05
repair mortar from 1980

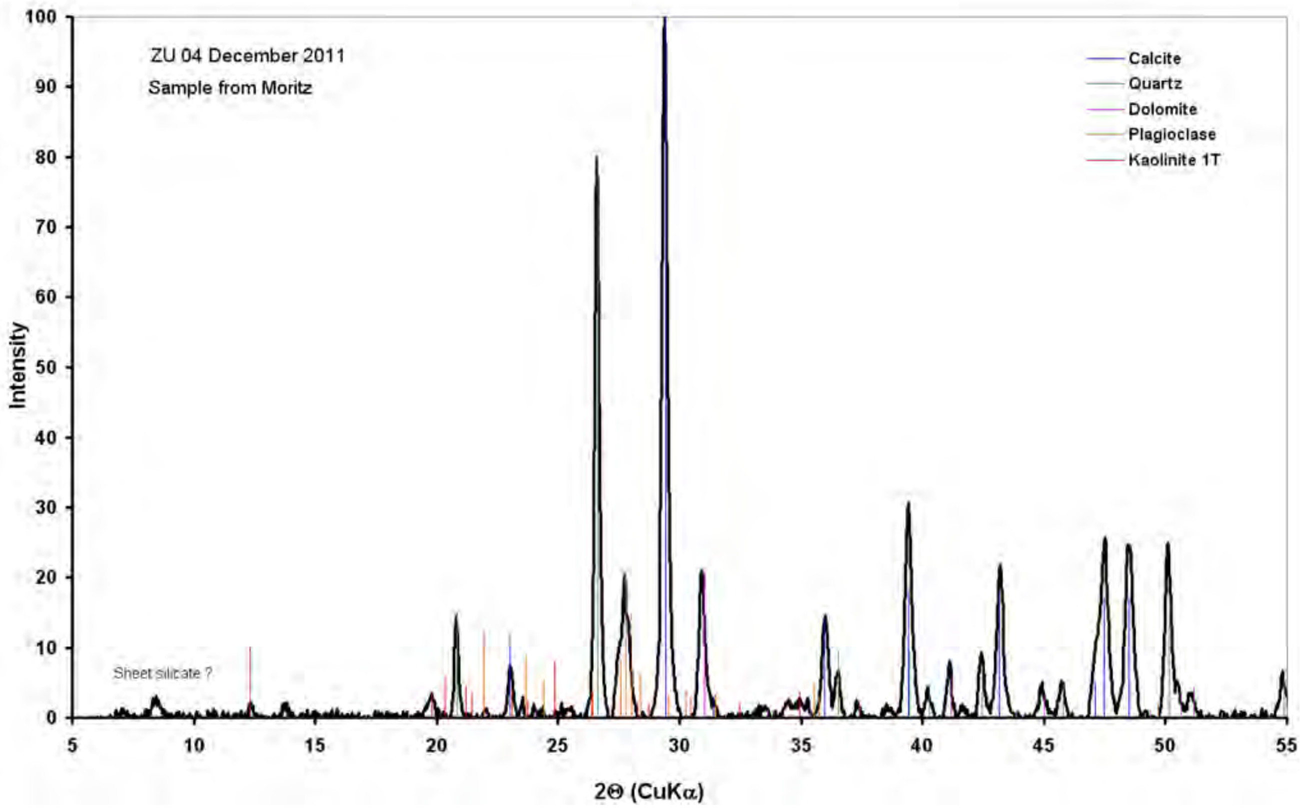
ZU 06  wall mortar

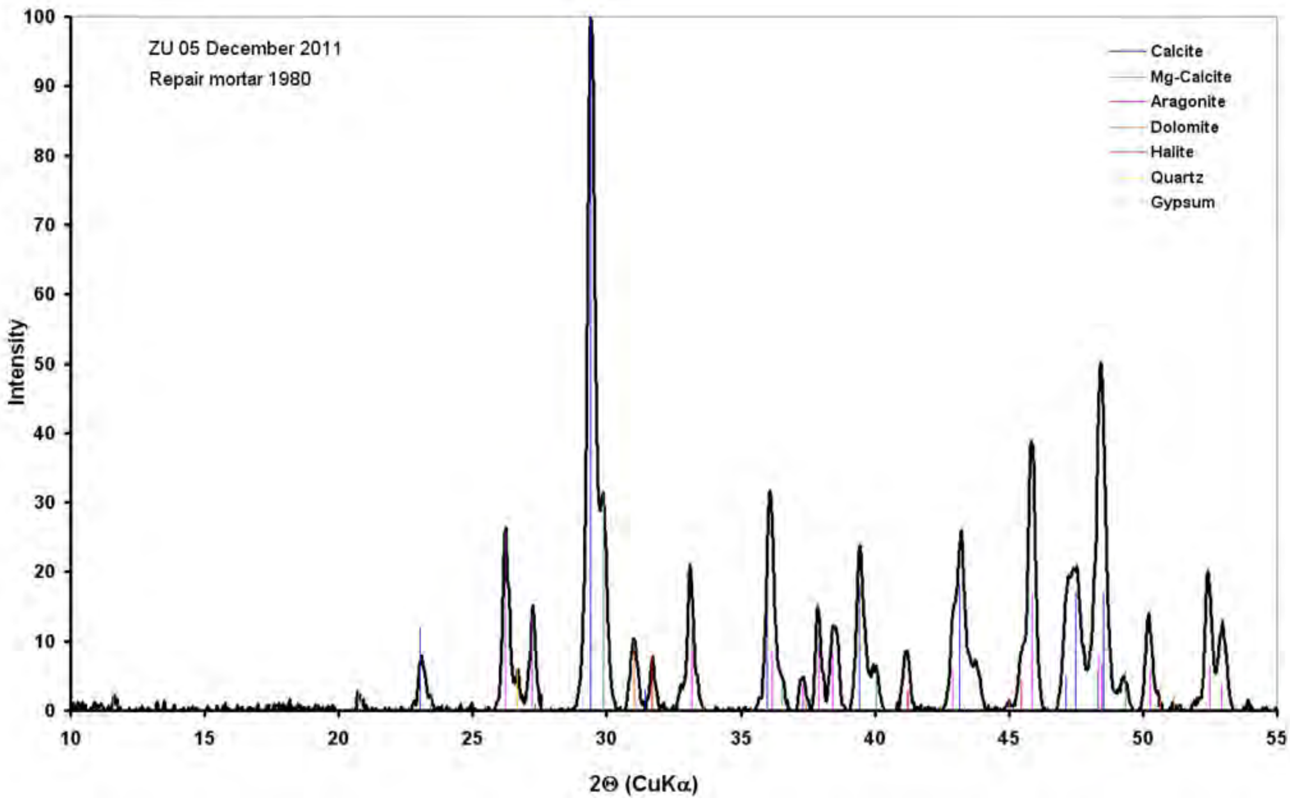
ZU 09  wall mortar

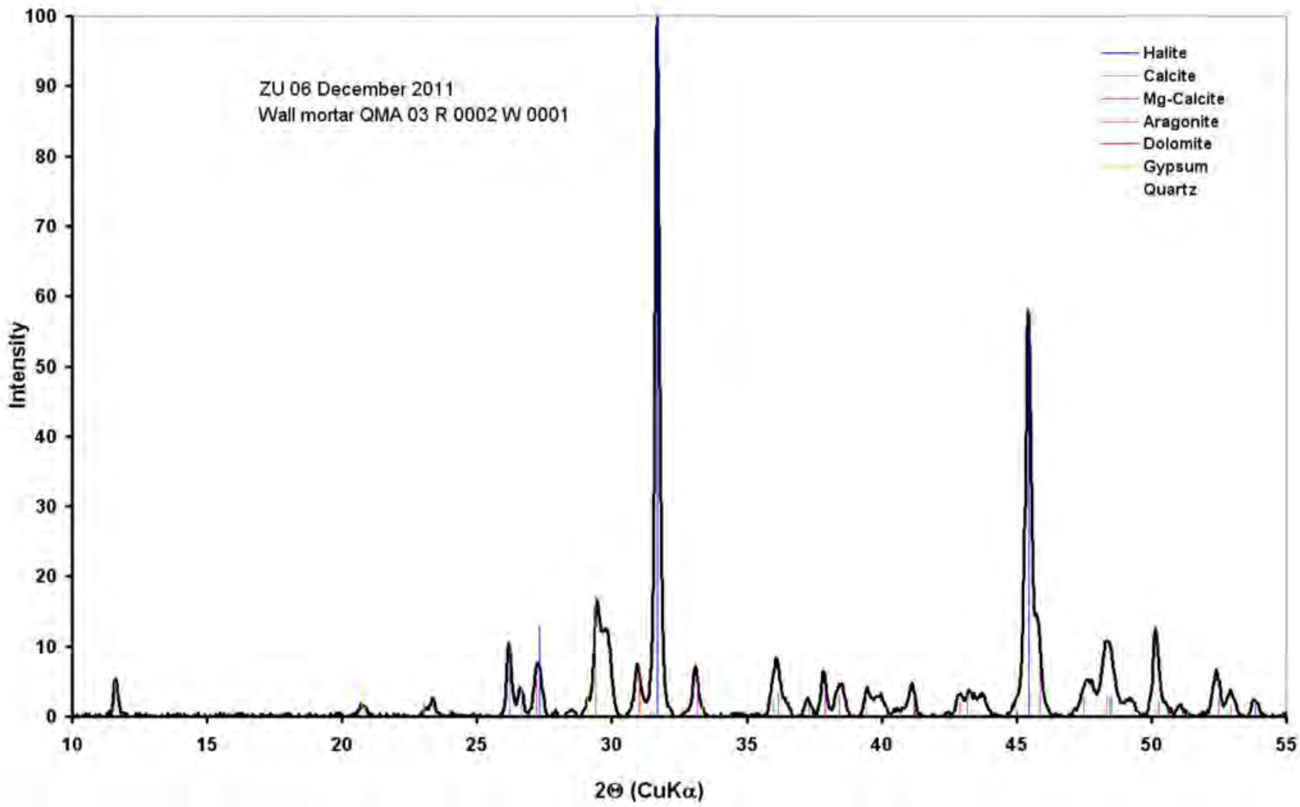


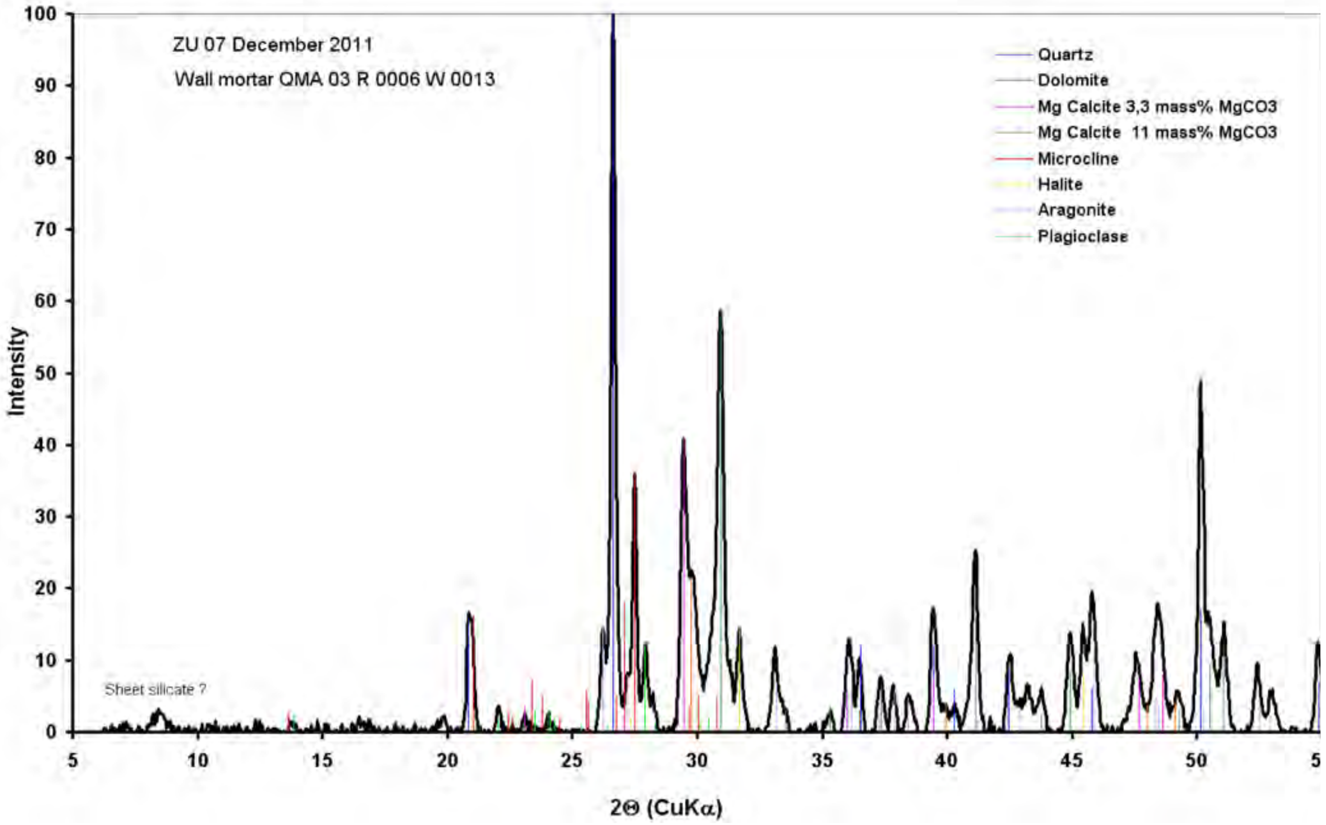
ZU 19 gypsum mortar QMA 02

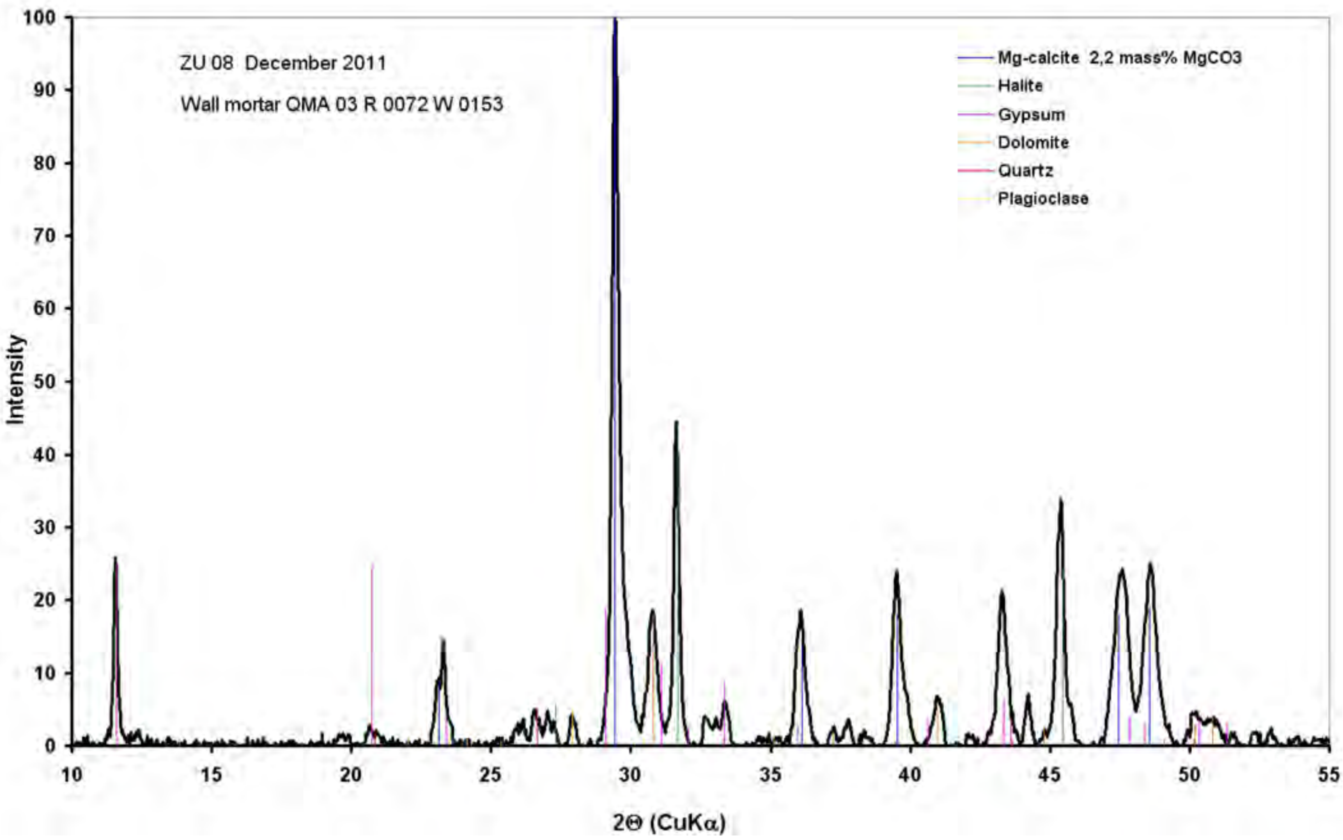

Sample ZU 01 Dec 2011
Upper layer of gypsum plaster
Gypsum
Calcite
Quartz
Anhydrite
Microcline
Intensity
2Θ (CuKα)

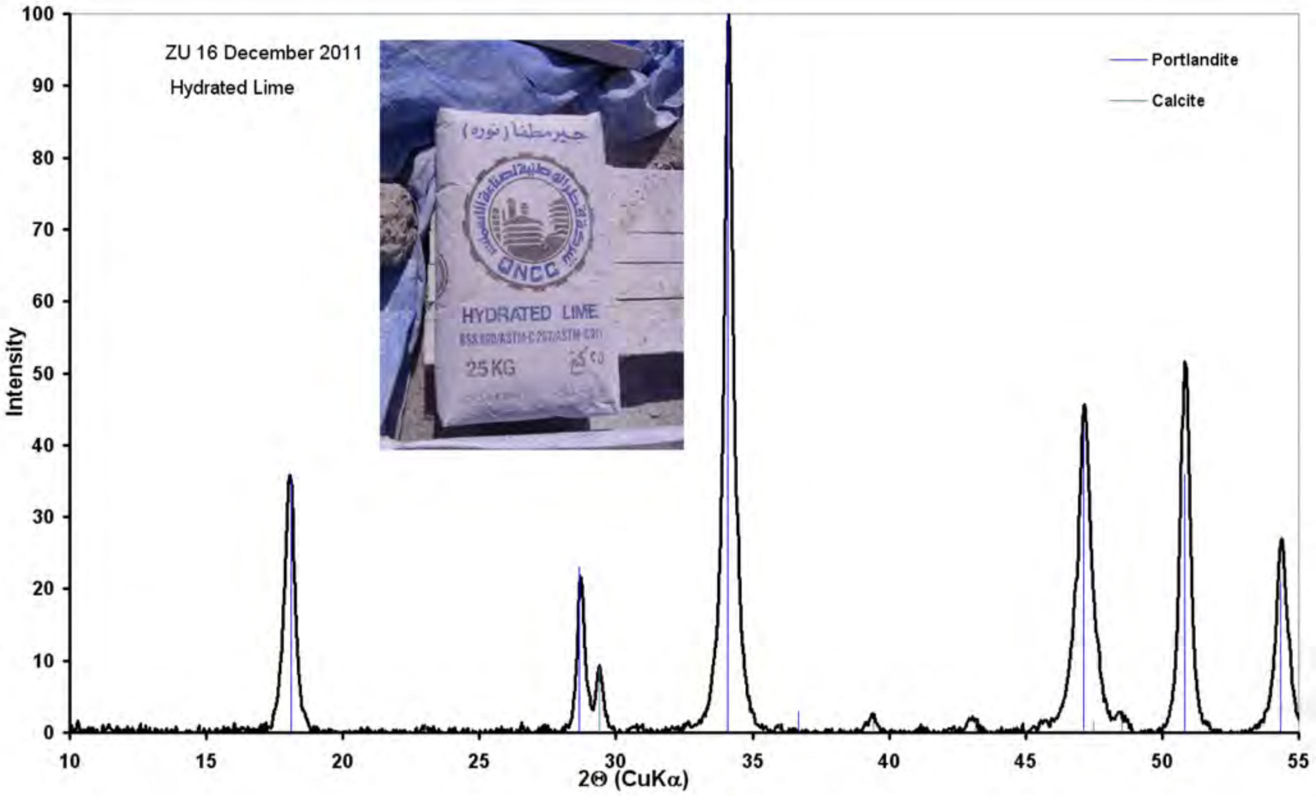

ZU 04 December 2011
Sample from Moritz
Calcite
Quartz
Dolomite
Plagioclase
Kaolinite 1T
Sheet silicate ?
Intensity
2Θ (CuKα)

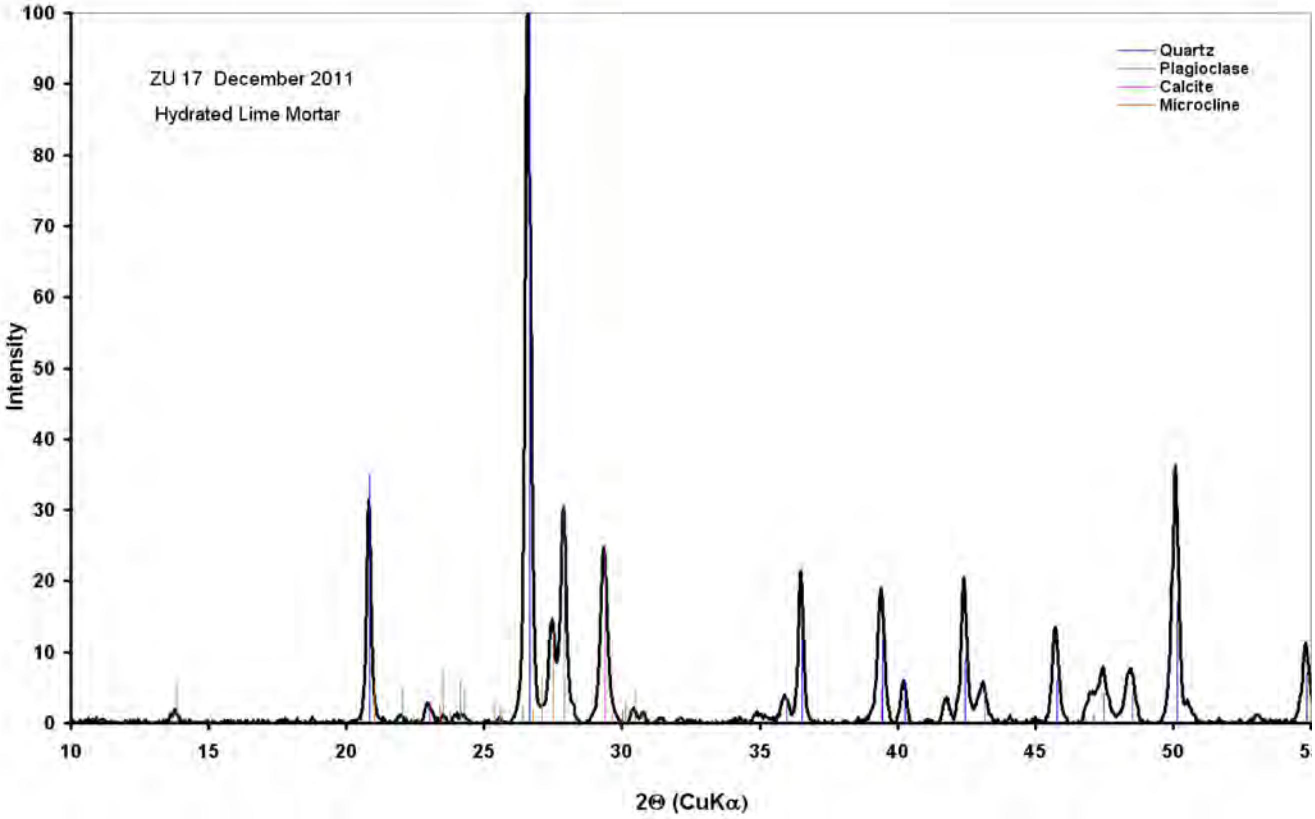

ZU 05 December 2011
Repair mortar 1980
Calcite
Mg-Calcite
Aragonite
Dolomite
Halite
Quartz
Gypsum
Intensity
2Θ (CuKα)

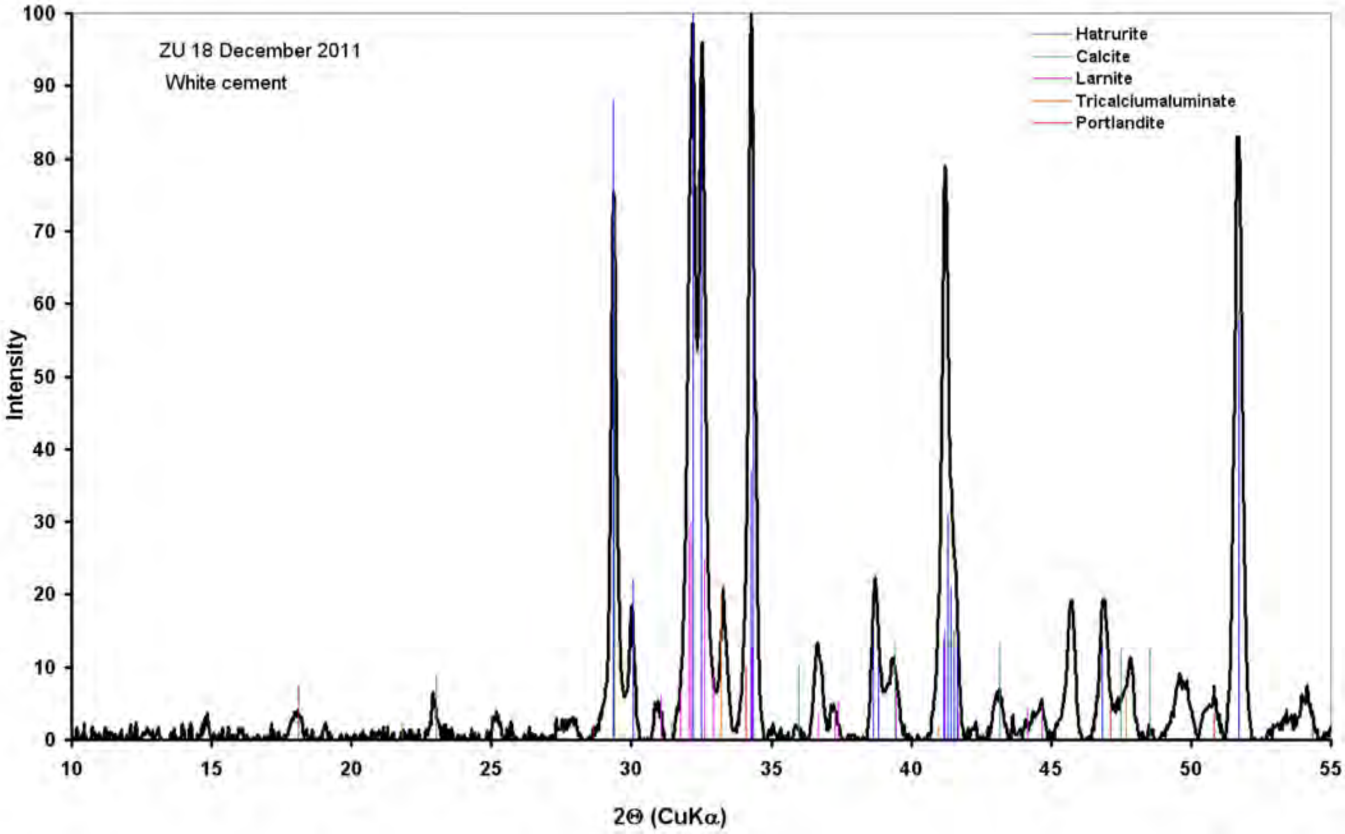

ZU 06 December 2011
Wall mortar QMA 03 R 0002 W 0001
Halite
Calcite
Mg-Calcite
Aragonite
Dolomite
Gypsum
Quartz
Intensity
2Θ (CuKα)

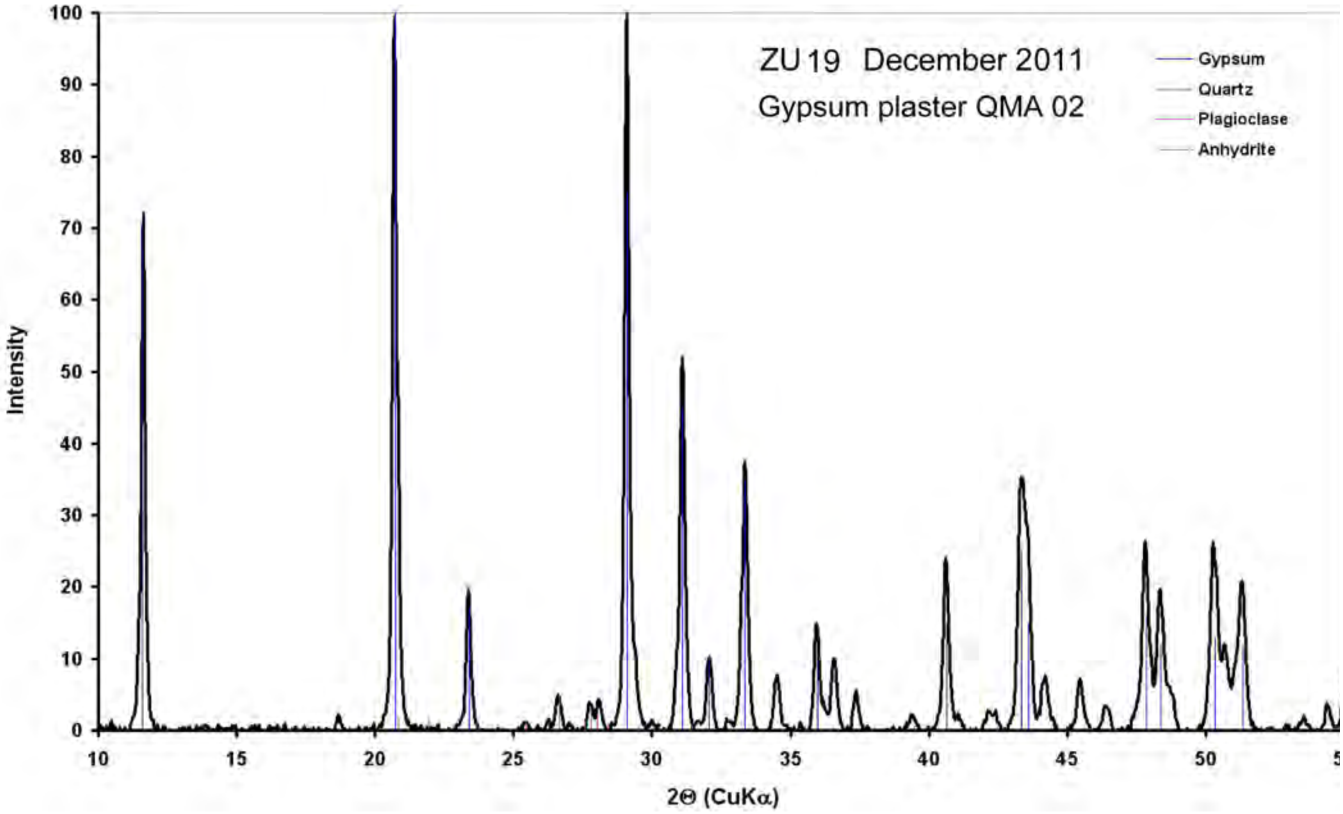

ZU 07 December 2011
Wall mortar QMA 03 R 0006 W 0013
Quartz
Dolomite
Mg Calcite 3,3 mass% MgCO3
Mg Calcite 11 mass% MgCO3
Microcline
Halite
Aragonite
Plagioclase
Sheet silicate ?
Intensity
2Θ (CuKα)

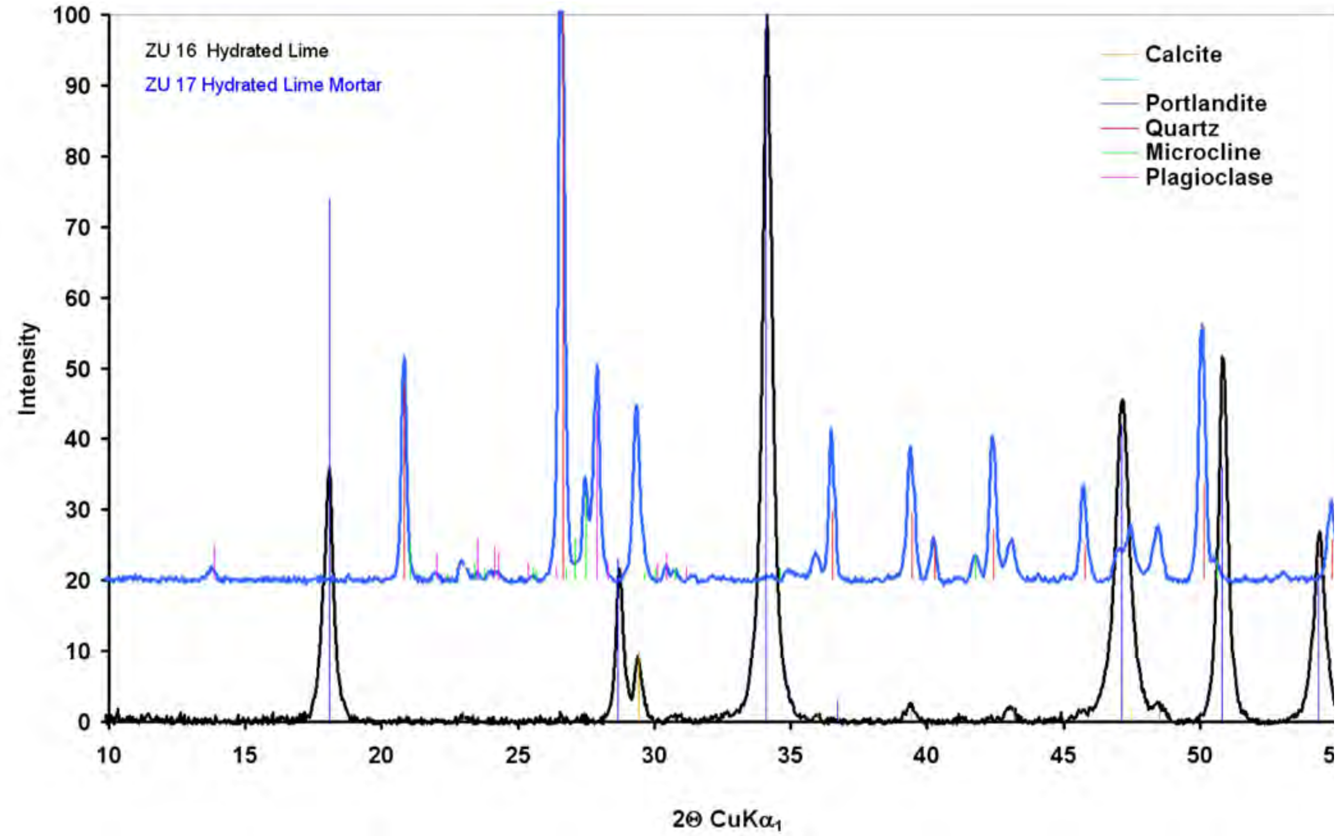

ZU 08 December 2011
Wall mortar QMA 03 R 0072 W 0153
Mg-calcite 2,2 mass% MgCO3
Halite
Gypsum
Dolomite
Quartz
Plagioclase
Intensity
2Θ (CuKα)


ZU 16 December 2011
Hydrated Lime
HYDRATED LIME
25 KG
QNCC
Portlandite
Calcite
Intensity
2Θ (CuKα)
0
10
20
30
40
50
60
70
80
90
100
10
15
20
25
30
35
40
45
50
55


ZU 17 December 2011
Hydrated Lime Mortar
Quartz
Plagioclase
Calcite
Microcline
Intensity
2Θ (CuKα)
0
10
20
30
40
50
60
70
80
90
100
10
15
20
25
30
35
40
45
50
5


ZU 18 December 2011
White cement
Hatrurite
Calcite
Larnite
Tricalciumaluminate
Portlandite
Intensity
2Θ (CuKα)


ZU 19 December 2011
Gypsum plaster QMA 02
Gypsum
Quartz
Plagioclase
Anhydrite
Intensity
2Θ (CuKα)




**The hardening reaction of a lime mortar**

Sand (quartz, microcline, plagioclase) + lime + $CO_2$ → Calcite + Sand

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

## Comments to the results of the X-ray diffraction study of various samples:

| No. | 12 - 2012 Sample Code | Description | X-ray diffraction | Chemical analysis | Phase composition |
|---|---|---|---|---|---|
| 1 | | Upper layer of gypsum plaster | X | | Gyp, Cc, Mic, Qtz, Anh |
| 2 | | Fort Sikrit Wall and Joint mortar 27.10.2011 | | | |
| 3 | | Repair Mortar 1980 | | | |
| 4 | | sample from MoritzMoritz | X | | Cc, Qtz, Dol, Plg, Kao, sheet silicate ? |
| 5 | | Repair Mortar 1980 | X | | Cc, Mg Cc, Ara, Dol, Hal, Qtz, Gyp |
| 6 | ZU QMA 03 R 0002 W 0001 | Wall and Joint mortar | X | X | Hal, Cc, Mg Cc, Ara, Dol, Gyp Qtz |
| 7 | ZU QMA 03 R 0006 W 0013 | Wall and Joint mortar | X | X | Qtz, Dol, Mg Cc I + II, Mic, Hal, Ara, Plg |
| 8 | ZU QMA 03 R 0072 W 0153 | Wall and Joint mortar | X | X | Mg Cc, Hal, Gyp, Dol, Qtz, Plg |
| 9 | EP 04 | Sand 1 | | X | |
| 10 | EP 04 | Sand 2 | | X | |
| 11 | EP 04 | Sand 3 | | X | |
| 12 | EP 04 | South tower plaster 30.11.2011 | X | X | |
| 13 | ZU QMA 03 R? W 131/132 | Wall and Joint mortar | | X | |
| 14 | ZU QMA 03 R 0072 W 0153 | Wall and Joint mortar | | X | |
| 15 | P 1.32 | "salt" mortar | | X | |
| 16 | | Hydrated Lime | X | | Por, Cc |
| 17 | | Hydrated Lime Mortar | X | | Qtz, Plg, Cc, Mic |
| 18 | | White cement | X | | Hat, Cc, Lar, Tca, Por |
| 19 | QMA 02 | Gypsum plaster/mortar | X | | Gyp, Qtz, Plg, Anh |

**Sulfates:** Gyp: gypsum, , Anh: anhydrite
**Carbonates:** Cc: calcite, Ara: aragoste, Mg Cc: Mg calcite, Dol: dolomite
**Silicates:** Qtz: quartz, Mic: microcline, Plg: plagioclase, Kao : Kaolinite
**Halides:** Hal: halite
**Binding phases:** Hat: hatrurite, Lar: larnite, Brm: brownmillerite, Tca: tricalciumaluminate, Por: portlandite

**Major component:** Abc, Abc [ 75 – 100; 51 – 74 ]
**Minor component:** Abc, Abc [ 30 - 50; 6 - 29 ]
**Trace component:** Abc [ 0 - 5 ]

**The components quartz, microcline, and plagioclase are typical for sand aggregate, the components aragonite and Mg calcite for beach sand aggregate, and the component dolomite for fragments of Dammam dolomite. Calcite is the only by X-ray diffraction traceable phase representing the binding component in lime, natural hydraulic lime and cement mortars. Gypsum and anhydrite are typical for anhydrite/gypsum plaster. Anhydrite in gypsum plaster is regarded as an indication for an incomplete transformation to gypsum, thus indicating that anhydrite was the original binding material. The presence of calcite in gypsum plaster could mean that the original anhydrite mortar contained some lime (portlandite) as accelerator for the transformation reaction.**

# APPENDIX 7
# X-ray diffraction and chemical analysis of samples from the archaeological site Al Zubarah in Qatar

Two Reports by Robert Sobott
March 2010

Dr. Hans Ettl
Dr. Ludwig Sattler
Dr. Horst Schuh
Dr. Robert Sobott

# X-ray diffraction and chemical analysis of samples from the archaeological site Al Zubarah in Quatar

**Report No. 10/2010**

**Client:** Restorer Paul Hofmann
Annenwalde No. 3
17268 Densow

**Date of completion :** 17. March 2010
**Text :** 3 pages, 2 tables, 1 figure
**Appendix :** 2 pages

## 1 Introduction

The Labor für Baudenkmalpflege Naumburg obtained a number of samples from the archaeological site Al Zubarah in Quatar from the restorer Paul Hofmann for the determination of the quantitative and/or qualitative composition. The samples are presented in figure 1.

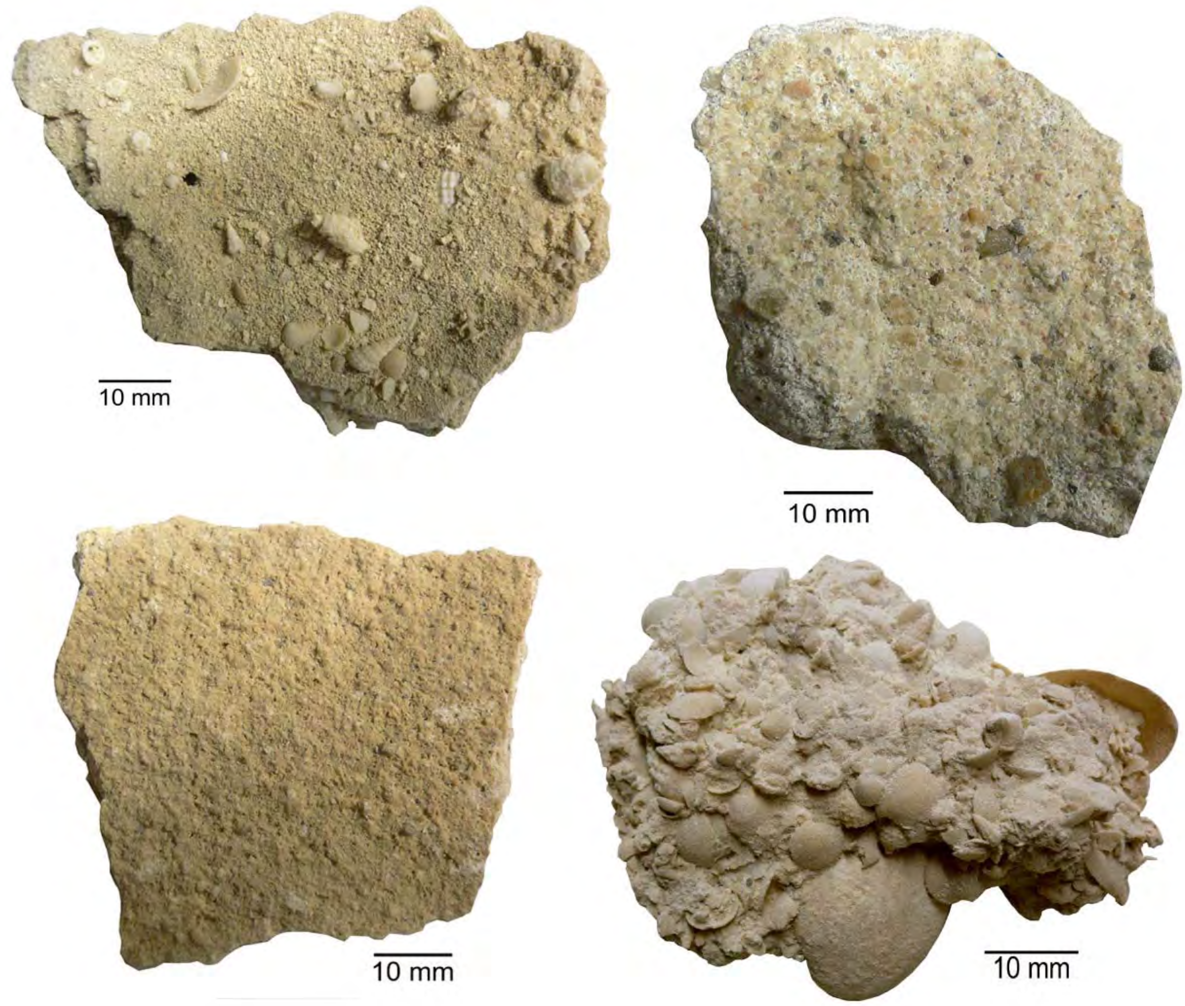



**Figure 1: Analysed samples. Top left: Sample No. 9 (soil-salt crust),**
**Top right: Sample No. 10 (lime mortar)**
**Bottom left: Sample No. 12 (wall plaster)**
**Bottom right: Sample No. 11 (beachrock)**

Quality and quantity of salts derived from the evaporation of sea water in sample no. 9, a soil-salt crust, were determined by X-ray diffraction and chemical analysis. The qualitative phase compositions of samples no. 10 and no. 12, a mortar and a render, were determined by X-ray diffraction analysis. The nomenclature of sample no. 11, which consists of shell debris weakly consolidated by calcite cement, is discussed.

## 2 Quantitative chemical analysis

Sample no. 9 was crushed, and the water-soluble salts were extracted with destilled water. The cations $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$ in the eluat were determined according to DIN EN (ICP-OES), the anions $Cl^-$, $SO_4^{2-}$, $NO_3^-$ according to DIN EN (ion chromatography). The results are given in table 1.

**Table 1: Soluble salt contents of sample no. 9 (salt-soil-crust)**

| **Sample No.** | **Sulfate** [Mass%] | **Nitrate** [Mass%] | **Chloride** [Mass%] | **Calcium** [Mass%] | **Magnesium** [Mass%] | **Sodium** [Mass%] | **Potassium** [Mass%] | **Total** [Mass%] |
|---|---|---|---|---|---|---|---|---|
| **9** | 2,82 | 0,00 | 19,70 | 1,05 | 0,16 | 9,00 | 0,10 | 32,82 |

## 3 X-ray diffraction analysis

When irradiated by X-rays crystalline substances generate a diagnostic diffraction pattern which can be used for phase identification.

Samples no. 9, 10, and 12 were ground in an agate mortar to a powder which was used for the analysis. The results are presented in table 2. The amount of the phases present in the mixtures is semi-quantitatively indicated by the letter size and bold writing (large and bold letters: main constitutent, middle-sized letters: minor constituent, etc.).

**Table 2: Phase composition of samples no. 9, 10, and 12**

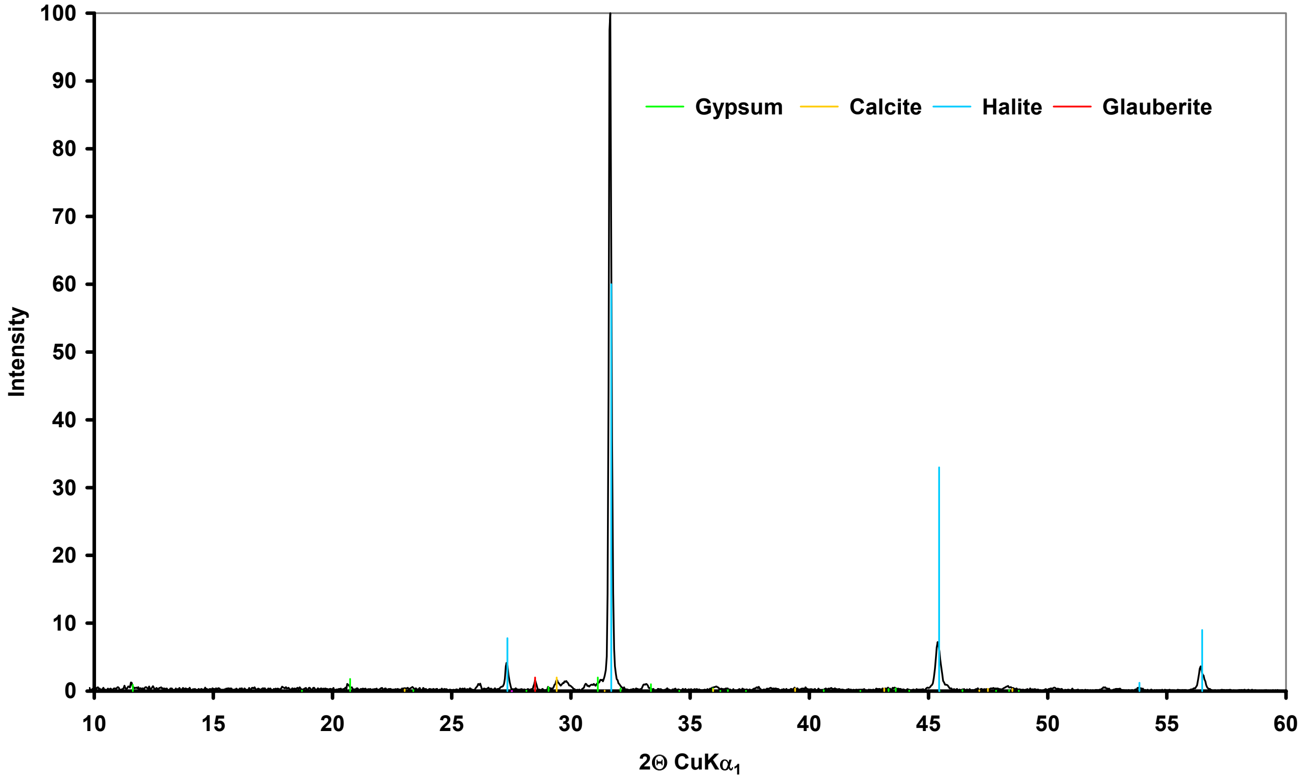
| **Sample No.** | **Phases** |
|---|---|
| 9 | **halite,** calcite, glauberite, gypsum, |
| 10 | **quartz**, calcite, microcline, plagioclase, gypsum |
| 12 | **gypsum**, calcite |

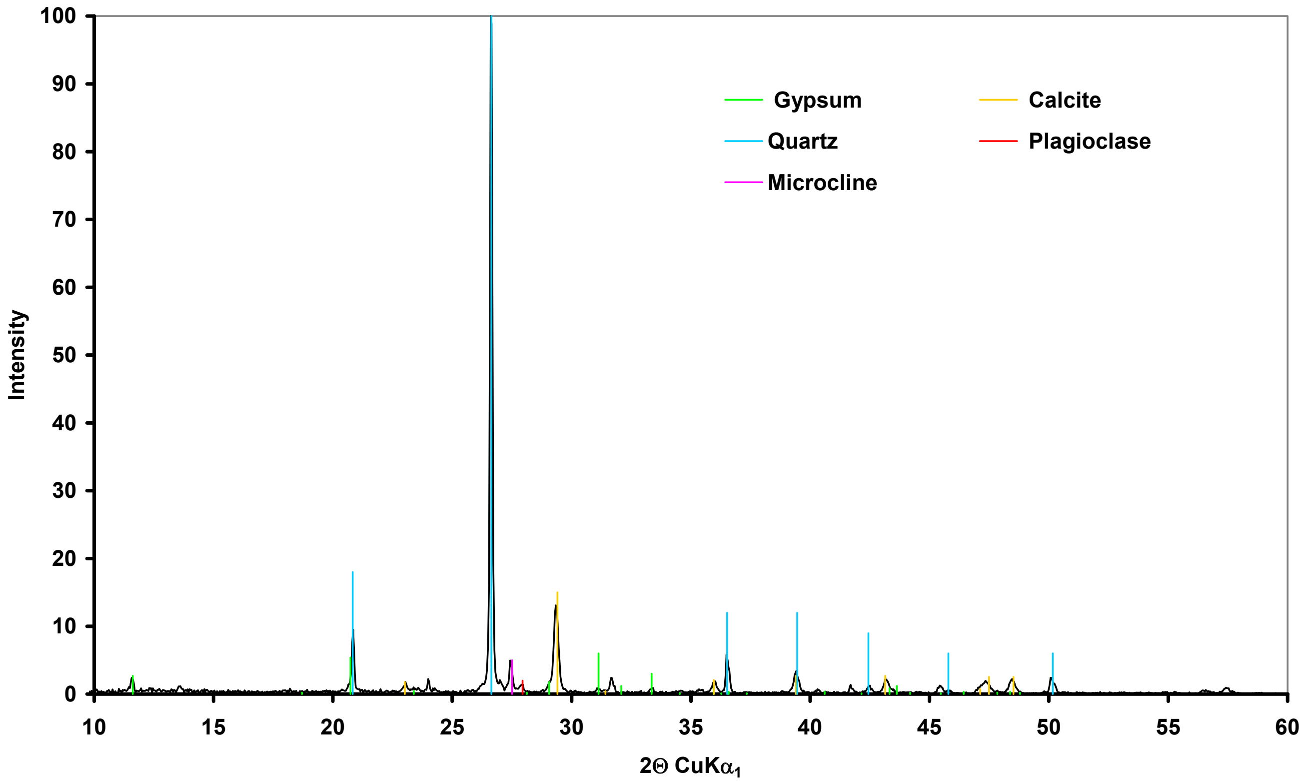
## 4 Discussion of results

According to the results of the X-ray diffraction and chemical analysis sample no. 9 contains around 29 mass% sodium chloride (halite). The contents of glauberite $Na_2Ca(SO_4)_2$, calcite $CaCO_3$, and gypsum $CaSO_4*2H_2O$ amount to 1 – 2 mass% each.

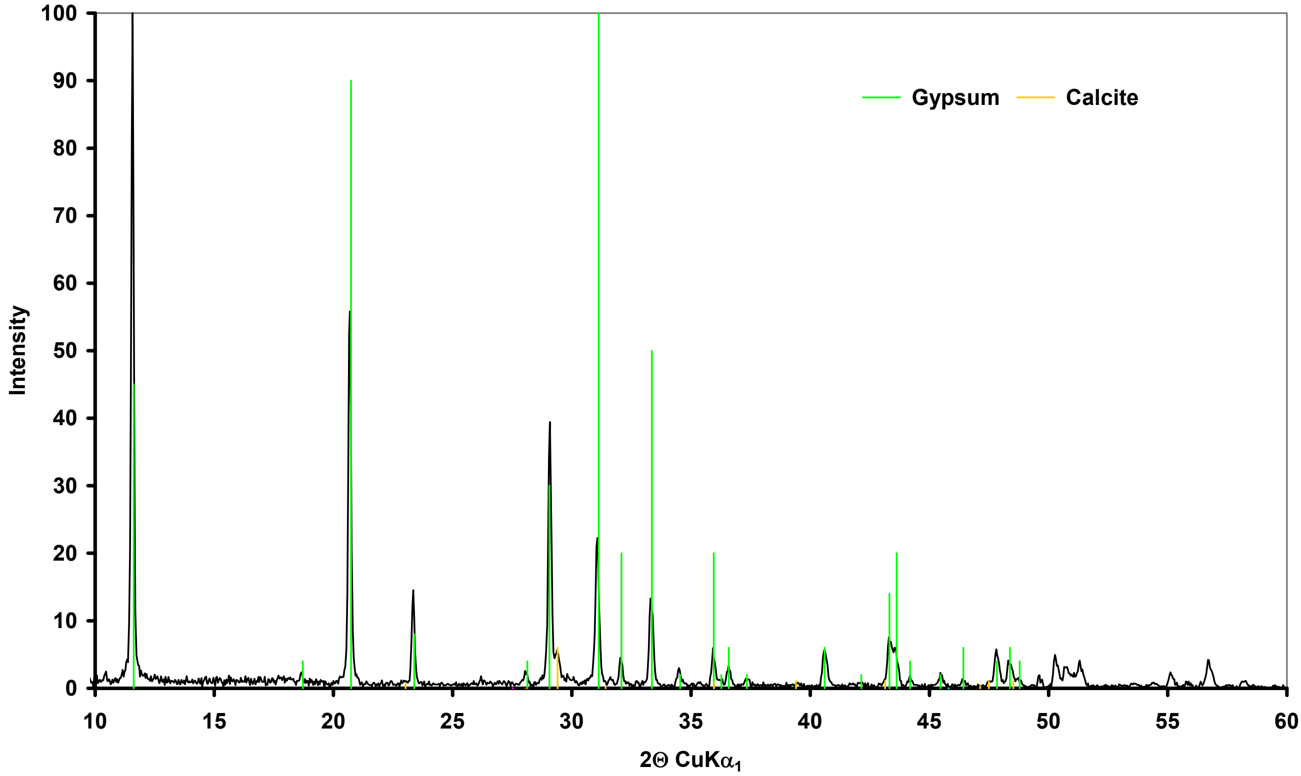
The X-ray diffraction analysis of the mortar sample no. 10 is typical for a lime mortar. However, the amount of binding material (calcite) is rather low and a small part of it has been transformed into gypsum. The render sample no. 12 consists almost entirely of gypsum with only minor amounts of calcite. The porosity of gypsum mortars can be very low so that the penetration of consolidating agents (e. g. silanes) is not sufficient to produce satisfactory results. It is suggested to do repair work on the gypsum render (wall plaster) with accordingly pigmented gypsum mortars.

According to the Glossary of Geology, edited by Bates & Jackson, American Geological Institute, Falls Church Virginia, 1980, 2nd edition, the term “beachrock” is quite appropriate. A beachrock is defined as a a friable to well-cemented sedimentary rock, formed in the intertidal zone in a tropical or subtropical region, consisting of sand or gravel (detrital and/or skeletal) cemented with calcite.




**X-ray diffraction diagrammes of samples No. 9 (salt-soil-crust; top) and No. 10 (mortar)**




**X-ray diffraction diagramme of sample No. 12 ( wall plaster)**

Dr. Hans Ettl
Dr. Ludwig Sattler
Dr. Horst Schuh
Dr. Robert Sobott

# X-ray diffraction and chemical analysis of samples from the archaeological site Al Zubarah in Qatar and preparation of a restoration mortar

**Report No. 10b/2010**

**Client:** Restorer Paul Hofmann
Annenwalde No. 3
17268 Densow

**Date of completion :** 13. June 2010
**Text :** 5 pages, 4 tables, 2 figures
**Appendix :** 1 page

## 1 Introduction

The Labor für Baudenkmalpflege Naumburg obtained a number of sand and mortar samples (figure 1) from the restorer Paul Hofmann in order to determine the chloride contents and phase composition, respectively. Two washed sand samples were used for the preparation of mortars with natural hydraulic lime as binder.

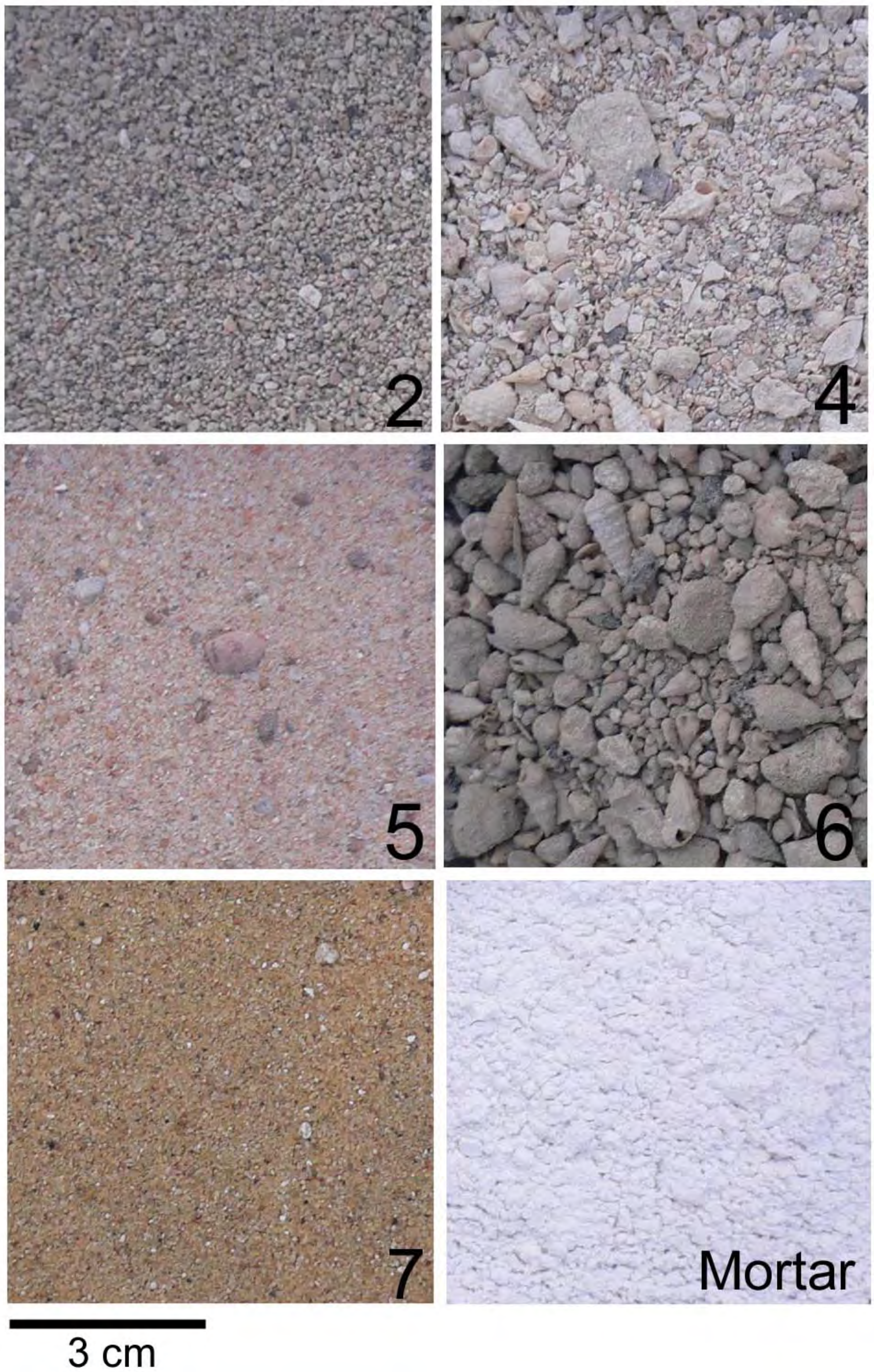



**Figure 1: Sand and mortar samples**

## 2 Quantitative chemical analysis of chloride content in sand samples

The chloride contents of seven untreated sand samples were determined according to DIN ISO 10304-1 (by ion chromatography). The samples with the largest chloride contents (No. 1 and 3) were flushed with a volume of tap water twice as large as the sand volume and dried. The remaining chloride contents were measured. The results are given in table 1.

**Table 1: Chloride contents in sand samples (data given in mass %)**

| | Sand samples | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | < 2mm | 0,75 – 2 mm | < 0,75 mm | > 2 mm | 0 – 4 mm | > 2mm | QMA |
| untreated samples | 1,96 | 1,66 | 1,95 | 1,24 | 0,04 | 1,07 | 0,02 |
| washed samples | 0,36 | - | 0,67 | - | - | - | - |

Data of table 1 shows that the local, shells containing sand contains a lot of sodium chloride which renders it as an unfavourable aggregate for the production of mortar. However, a single and simple washing procedure reduces the chloride contents effectively.

## 3 X-ray diffraction analysis

When irradiated by X-rays crystalline substances generate a diagnostic diffraction pattern which can be used for phase identification.

A mortar sample of unknown composition and supposedly produced by Pakistani workmen was investigated by this method. The identified phases in the compound are listed below, the diffraction diagram is presented in appendix 1.

**Table 2: Phase composition of unknown mortar**

| Sample | Phases |
|---|---|
| Mortar | anhydrite II, gypsum, calcite, bassanite, quartz |

According to the phase composition the investigated mortar is an anhydrite binder which is produced by firing gypsum in the temperature interval 320 - 480 °C. The presence of some gypsum and bassanite indicates that either the dehydration of gypsum was not totally complete or that part of the anhydrite II ($CaSO_4$) took up water and reacted back to bassanite ($CaSO_4$*0.5$H_2O$) and gypsum ($CaSO_4$*2$H_2O$). Quartz and calcite can be regarded as impurities of the raw material.

## 4 Preparation of restoration mortar

With the washed sand samples 1 and 3 two mortar samples were prepared with natural hydraulic lime (Otterbein Hydradur NHL 5) as binder. The composition of the mortars is given in table 3.

**Table 3: Mortar compositions**

| | |
|---|---|
| Sample 1 | 1 volume part NHL 5, 3 volume parts aggregate, 1 volume part water |
| Sample 3 | 1 volume part NHL 5, 3 volume parts aggregate, 2 volume parts water, 2 mass% tylose+) |

+) with reference to the combined mass of binder and aggregate

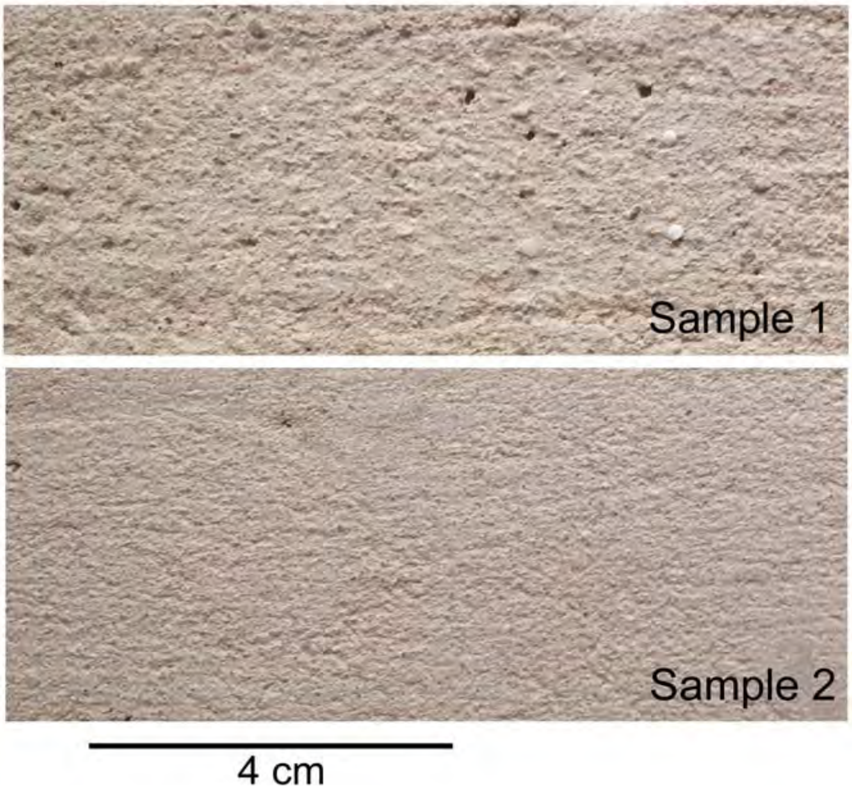



**Figure 2: Mortar samples 1 (sand charge 1) and 2 (sand charge 3)**

The addition of 2 mass% tylose to a mixture of 1 volume part binder and 3 volume parts aggregate doubles the amount of water which can be added to the mixture in order to produce a workable mortar. The tylose retains the water effectively, protracts the hardening process and may help to prevent the premature drying of the mortar in the arid climate at Al Zubarah. The physical parameters of the mortars are listed in table 4.

**Table 4: Physical parameters of mortar samples**

| Sample | Density [g/cm³] | Young's modulus [kN/mm²] | Compressive strength [N/mm²] |
|---|---|---|---|
| **1** | **1,45** | **1,8** | **1,5 +)** |
| **2** | **1,44** | **1,8** | **1,5 +)** |

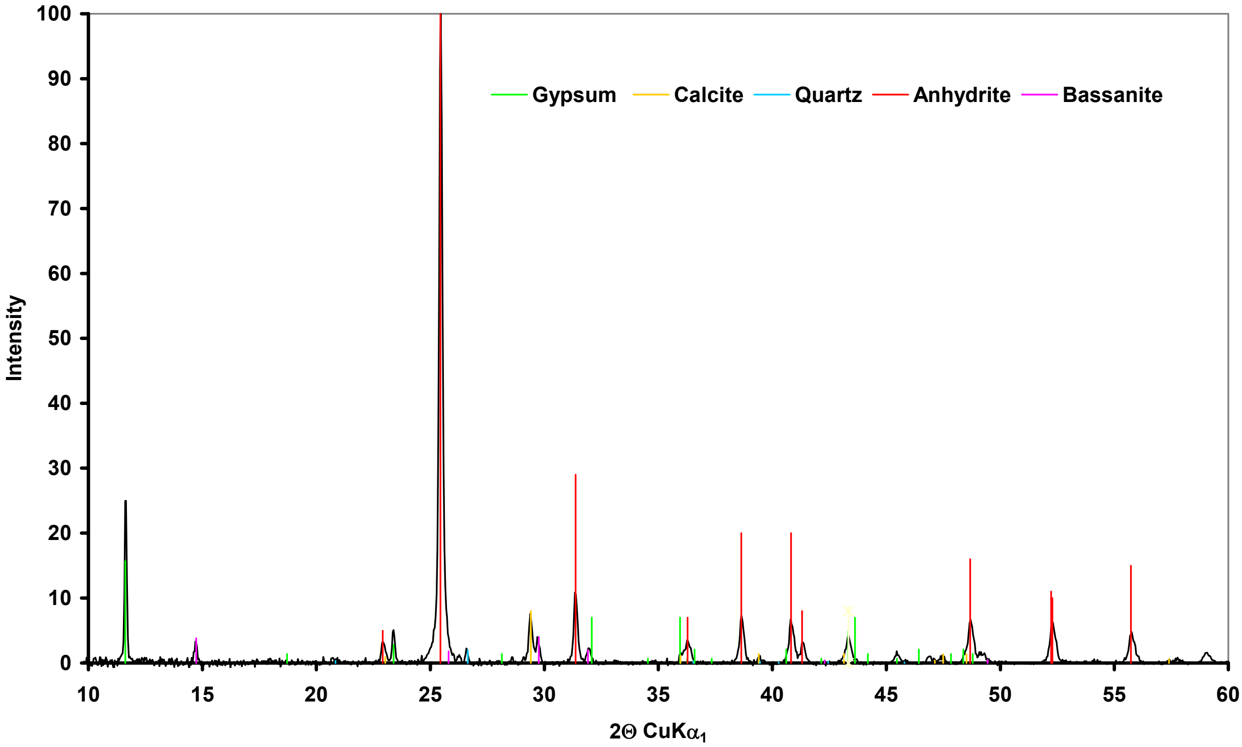
+) after 9 days of hardening. The compressive strength after 28 days is supposed to be higher than 2 N/mm².

## 5 Summary of results

The untreated sand from the beach contains a high amount of sodium chloride which makes it unfavourable for the use as aggregate for the production of mortar. However, the sodium chloride contents can be effectively reduced by a simple washing procedure which requires about double the volume of the sand. If large volumes of sand have to be washed it may be reasonable to desalt the process water so that it can be used several times.

The X-rayed mortar proved to be an anhydrite mortar. Under arid climate conditions anhydrite mortar may be a good alternative to lime mortar.

The addition of about 2 mass% tylose to the aggregate/binder mixture almost doubles the amount of water which the mortar can take up and consequently reduces the risk of premature drying. The physical parameters of a tylose containing mortar are similar to that of a tylose-free mortar. The “classical mixture” of 1 volume part binder (NHL 5), 3 volume parts aggregate and about 1 volume part of water will yield a mortar with a compressive strength of about 2 – 3 N/mm² after 28 days of hardening. In order to increase the compressive strength the water volume may be reduced but that will produce a friable mortar paste which is not so workable and has a higher risk of premature drying.




X-ray diffraction diagram of mortar sample

APPENDIX 8

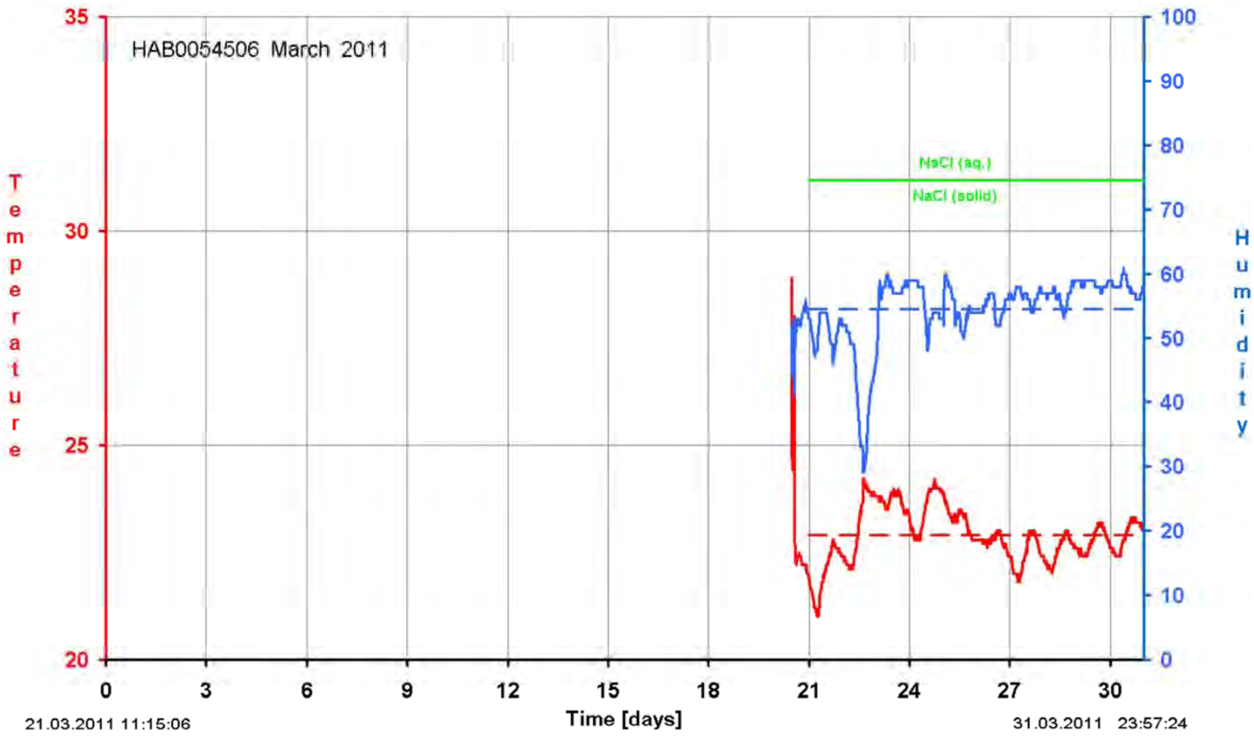
# CLIMATE DATE RECORD

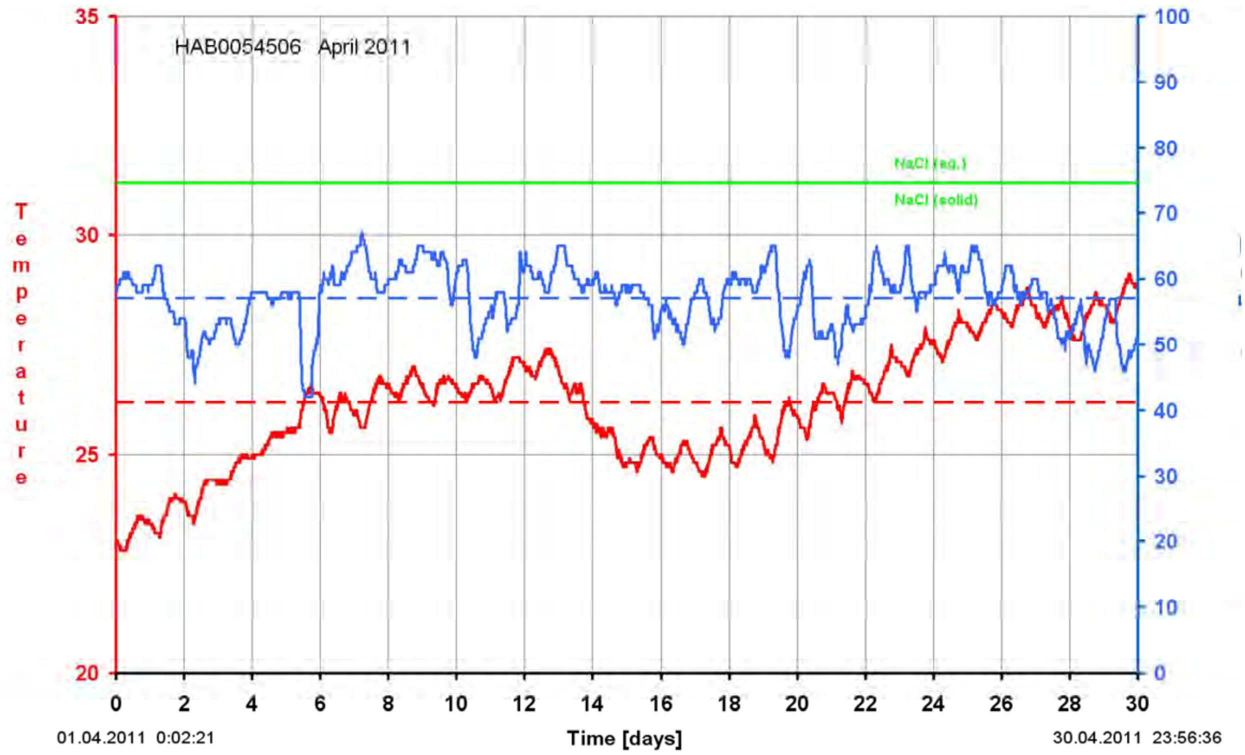
## AT AL ZUBARAH FORT / QATAR

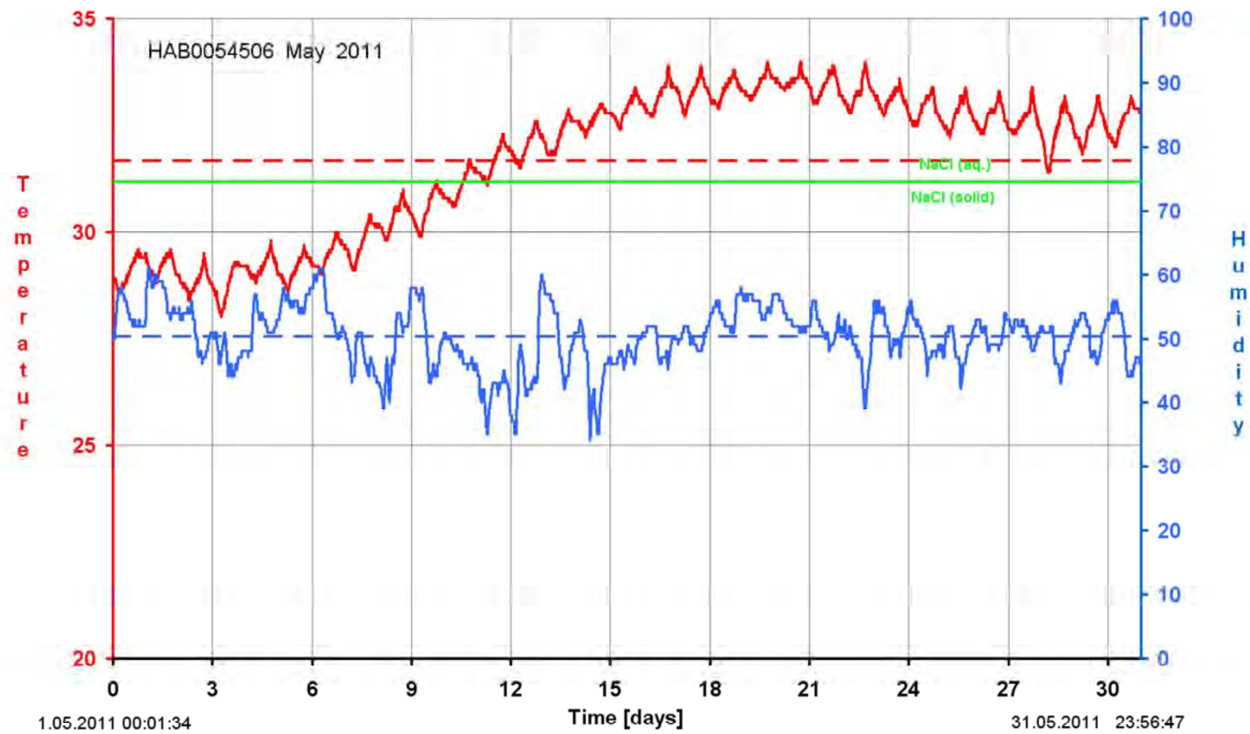
## March 2011 - September 2011

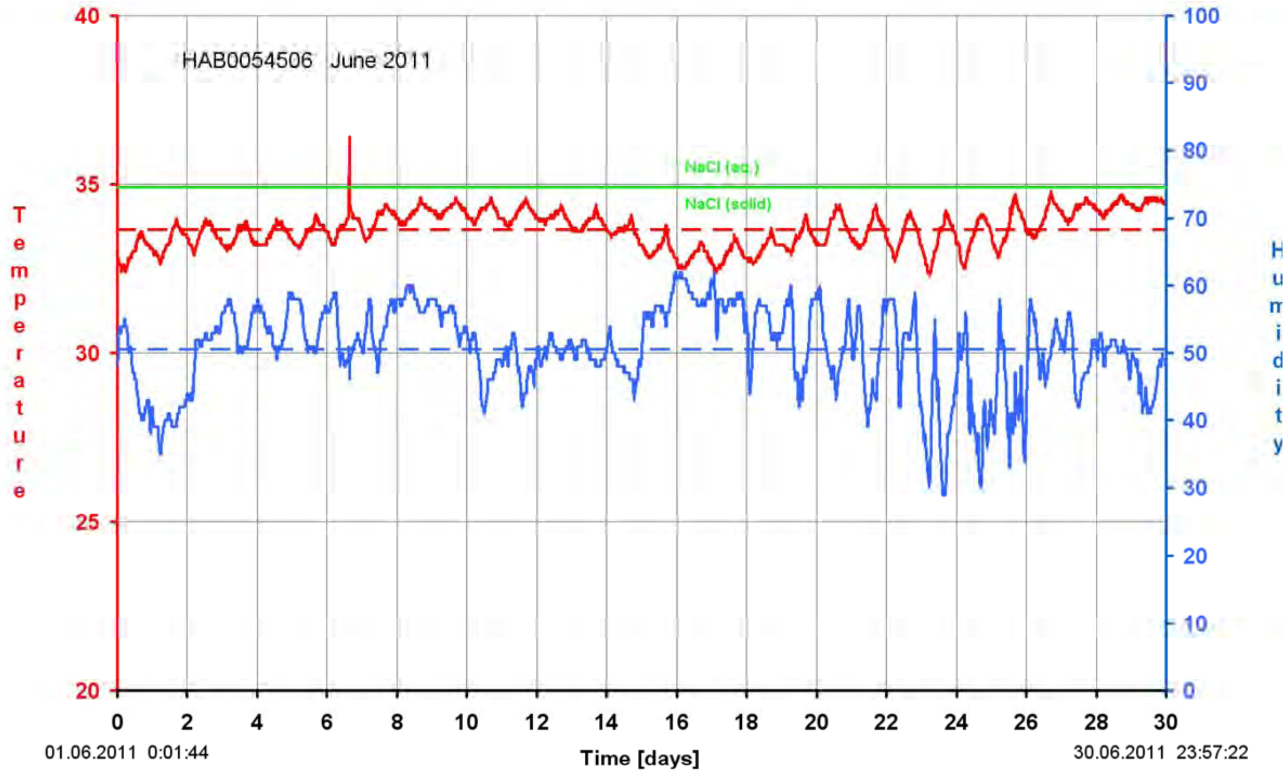
processed by R. Sobott
July 2012

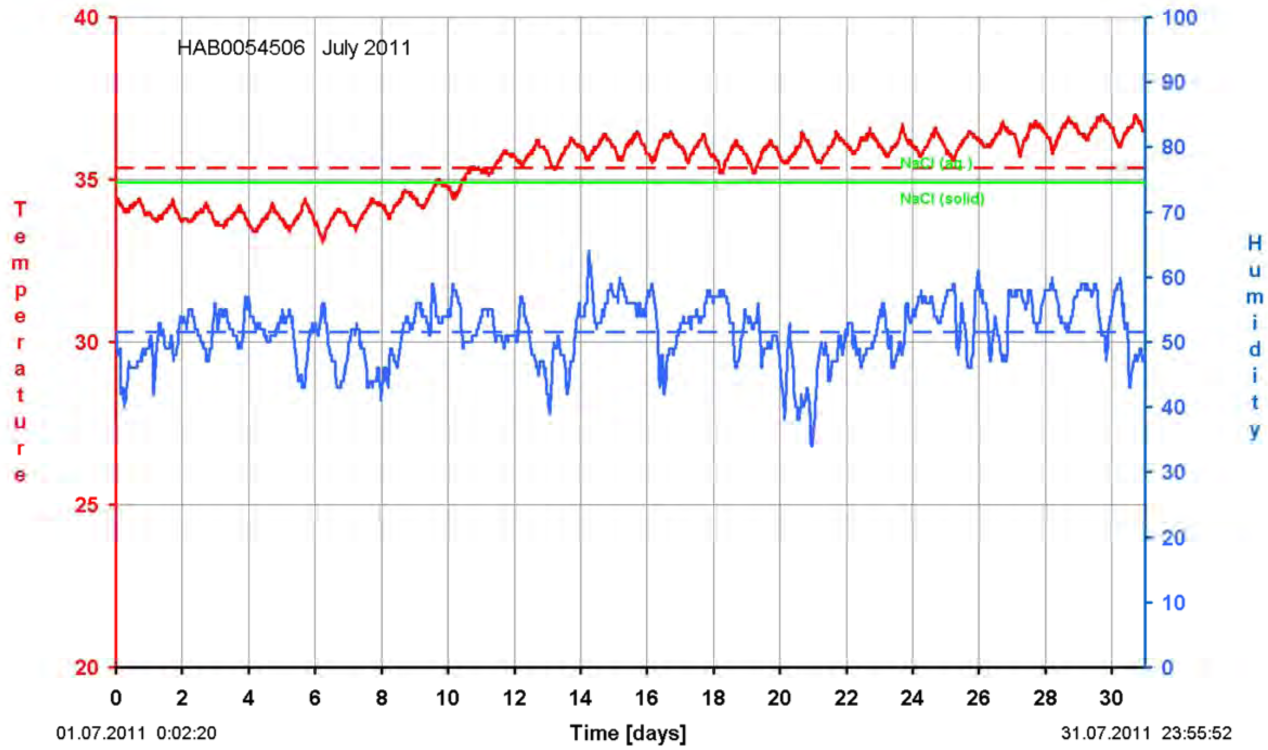
| | | | | | | |
|---|---|---|---|---|---|---|
| **Data Logger** | | **Location:** | Al Zubarah Fort inside room | | | |
| | | **Serial number :** | HAB0054506 | | | |
| **Number of data:** | | 53243 | equivalent to | 179 | days and | 13,05 | hours |
| **Sampling interval :** | | 4,85 | min | | | |
| **Start of data recording :** | | | 21.03.2011 | 11:15:06 | | |
| **End of data recording :** | | | 20.09.2011 | 22:52:49 | | |
| **Maximum Temperature:** | | 37,2 | **Minimum Humidity :** | 67,0 | | |
| **Minimum Temperature :** | | 21,0 | **Minimum Humidity :** | 29,0 | | |
| **Av. Temperature March :** | | 22,9 | **Av. Humidity March :** | 54,4 | | |
| **Av. Temperature April :** | | 26,2 | **Av. Humidity April :** | 57,1 | | |
| **Av. Temperature May :** | | 31,7 | **Av. Humidity May :** | 50,3 | | |
| **Av. Temperature June :** | | 33,7 | **Av. Humidity June :** | 50,6 | | |
| **Av. Temperature July :** | | 35,4 | **Av. Humidity July :** | 51,5 | | |
| **Av. Temperature August :** | | 36,2 | **Av. Humidity August :** | 51,5 | | |
| **Av. Temperature September :** | | 34,7 | **Av. Humidity September :** | 51,5 | | |

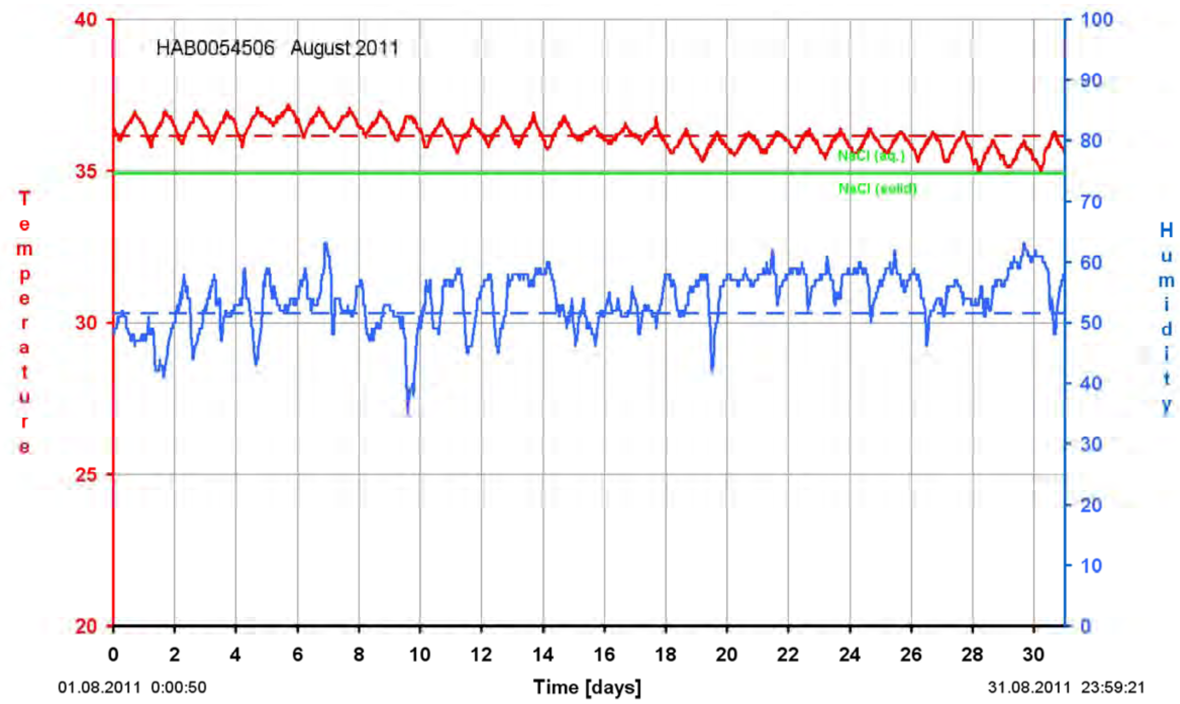


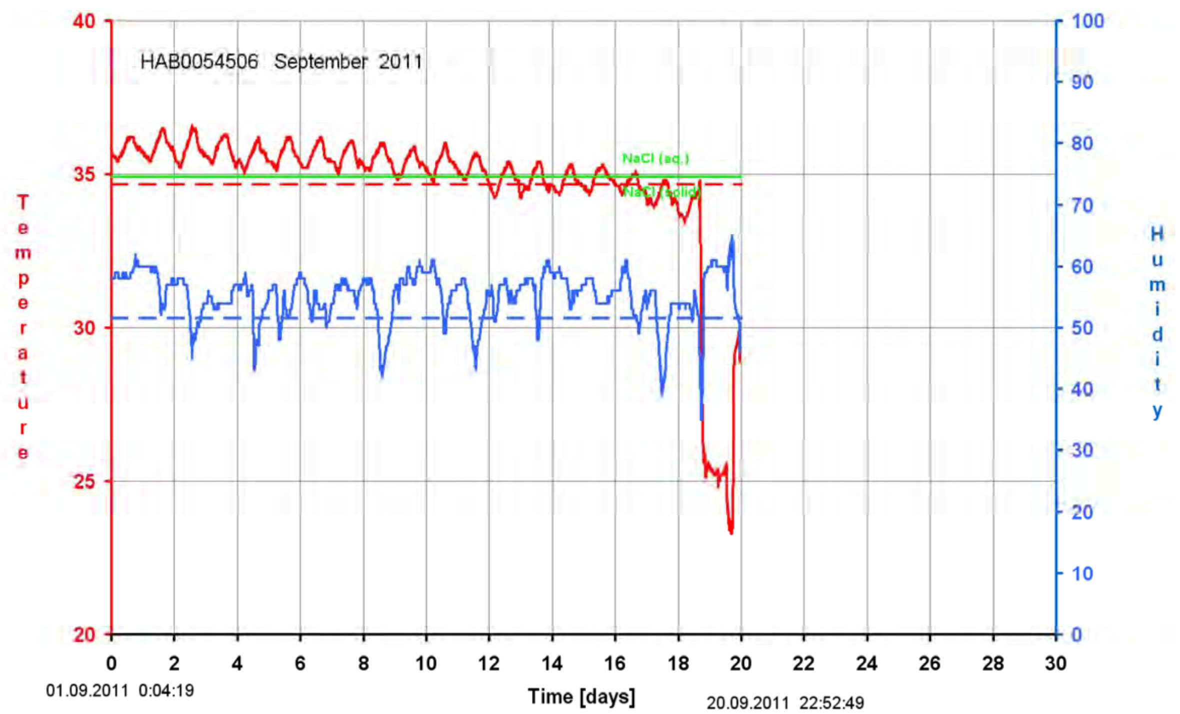

HAB0054506 April 2011
NaCl (aq.)
NaCl (solid)
Temperature
Time [days]
01.04.2011 0:02:21
30.04.2011 23:56:36


HAB0054506 May 2011
NaCl (aq.)
NaCl (solid)
Temperature
Humidity
Time [days]
1.05.2011 00:01:34
31.05.2011 23:56:47


HAB0054506 June 2011
NaCl (aq.)
NaCl (solid)
Temperature
Humidity
Time [days]
01.06.2011 0:01:44
30.06.2011 23:57:22


HAB0054506 July 2011
NaCl (aq.)
NaCl (solid)
Temperature
Humidity
Time [days]
01.07.2011 0:02:20
31.07.2011 23:55:52


HAB0054506 August 2011
Temperature
Humidity
NaCl (aq.)
NaCl (solid)
Time [days]
01.08.2011 0:00:50
31.08.2011 23:59:21


HAB0054506 September 2011
Temperature
Humidity
NaCl (aq.)
NaCl (solid)
Time [days]
01.09.2011 0:04:19
20.09.2011 22:52:49

# APPENDIX 9

# TEMPLATES & FORMS

## FOR RECORDING, MONITORING AND REPORTING

# APPENDIX 9
# LIST OF TEMPLATES and FORMS

9.1 Visitor Log Sheet
9.2 Damage Report
9.3 Site Journal
9.4 Site Journal VAR. 2011/2012
9.5 Record sheet for fractures in mortars
9.6 Record sheet for Architectural Documentation

APPENDIX 9.1 VISITOR LOG

## QMA AL ZUBARAH ARCHAEOLOGICAL SITE VISITOR LOG SHEET

| SITE: | Al Zubarah town | Al Zubarah Fort |
|---|---|---|
| MONTH / YEAR: | | |

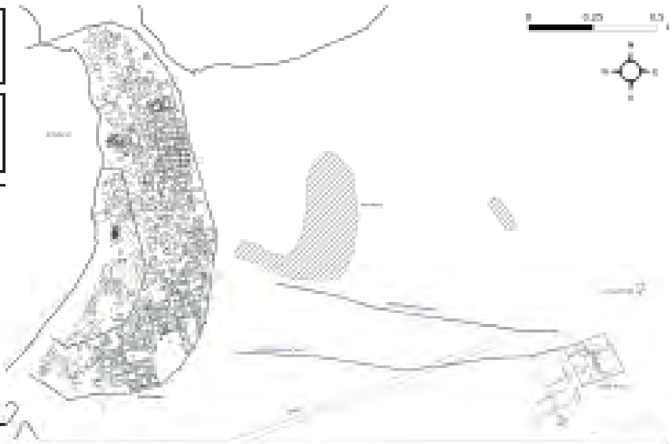
| S.N. | DATE | NO. OF VEHICLES | NO. OF CHILDREN | NO. OF MALES | NO. OF FEMALES | TOTAL OF VISITORS | REMARKS |
|---|---|---|---|---|---|---|---|
| | 1 | | | | | | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 7 | | | | | | |
| | 8 | | | | | | |
| | 9 | | | | | | |
| | 10 | | | | | | |
| | 11 | | | | | | |
| | 12 | | | | | | |
| | 13 | | | | | | |
| | 14 | | | | | | |
| | 15 | | | | | | |
| | 16 | | | | | | |
| | 17 | | | | | | |
| | 18 | | | | | | |
| | 19 | | | | | | |
| | 20 | | | | | | |
| | 21 | | | | | | |
| | 22 | | | | | | |
| | 23 | | | | | | |
| | 24 | | | | | | |
| | 25 | | | | | | |
| | 26 | | | | | | |
| | 27 | | | | | | |
| | 28 | | | | | | |
| | 29 | | | | | | |
| | 30 | | | | | | |
| | 31 | | | | | | |
| | | | | | | | |
| | **TOTAL** | | | | | | |

REPORTED BY: Staff No.

# AL ZUBARAH ARCHAEOLOGICAL SITE

Doc. No. QIAH-01-02-HE-

## REPORT ON DAMAGES



| |
|---|
| DATE: |
| REPORTED BY |
| LOCATION: |

| |
|---|
| DESCRIPTION OF DAMAGE (where, what, caused by, etc.) |

| |
|---|
| IMAGES |

AL ZUBARAH ARCHAEOLOGICAL SITE

# CONSERVATION SITE JOURNAL

## DAILY REPORT

Page 1 /

QIAH-01-02-HE-9_ _ _

SITE VISIT from [Day]; [Date]; [Time]

WEATHER: TEMPERATURE HUMIDITY

**ATTENDEES (inkl. workmen, craftspersons, etc.)**

**Materials status**
Hydrated Lime
NHL
White Cement
Quartz sand
Soil
Water

**LOCATION:**

**MEASURES, ACTIVITIES, WORK**
(planned for the day, as well as executed)

| DRAWINGS / DOCs related | Doc. No. | Content | Date | handed over to |
|---|---|---|---|---|
| | | | | |

**INADEQUACIES** (defects, cracks, detaching, etc)

**INSTRUCTIONS**

AL ZUBARAH ARCHAEOLOGICAL SITE

# CONSERVATION SITE JOURNAL

## DAILY REPORT

Page 2 /

QIAH-01-02-HE-0_ _ _

SITE VISIT from [Day]; [Date]; [Time]

| IMAGES | IMAGES |
| --- | --- |
| | |

SKETCH / COMMENTS

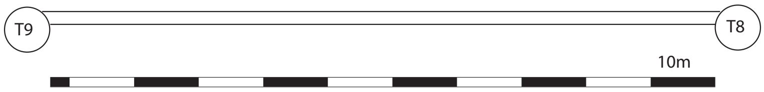
# QIAH-Conservation Site Journal

NOTES

| | Al Ruwais | Durkha |
|---|---|---|
| Weather | | |
| TEMP | | |
| HUMID | | |
| WIND | | |
| RAIN | | |

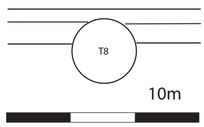
Bahrain:

WALLS

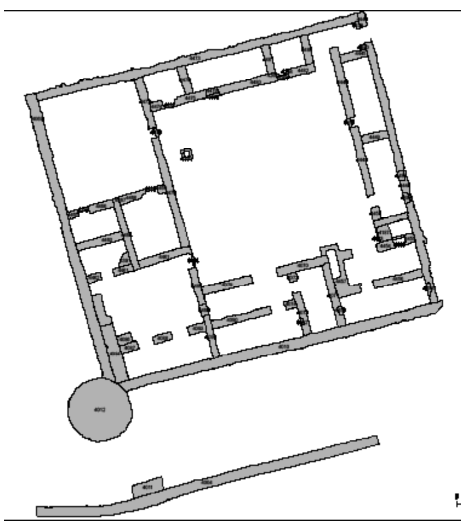



| | | |
|---|---|---|
| Hyd. Lime | | |
| White Cement | | |
| Sand | | |
| Water | | |
| | | |
| | | |

EP 10




EP 04



| | | |
|---|---|---|
| Hyd. Lime | | |
| White Cement | | |
| Sand | | |
| Water | | |
| | | |
| | | |

QIAH MONITORING Record sheet

Location: Date of Record:

## Fractures in mortars and concrete

**Shape** (linear, curved, reticulate):

**Width** (< 1mm, > 1mm):

**Depth** (< 5mm, > 5mm):

**Frequency** (singular, multiple):

**Location** (affected part of construction):

**Mortar composition** (especially water/cement ratio, aggregate size distribution):

**Constructive details** (thickness of mortar layer, reinforcement, connection to other parts of the construction, possibly with entirely different properties):

**Date of origin of cracks after curing**:

**Remarks** (temperature/humidity conditions during curing process, exceptional events during or after the execution of work):

**Photo documentation:**

**Main reasons for cracking**: shrinkage, stress-induced failure

| **QIAH - HERITAGE** | SITE: | | STRUCTURE: |
|---|---|---|---|
| | DATE: | SEASON: | Phase 1 Season1 |

**RELATIONS**

Related STRUCTURES:

Related ROOMS:

Related WALLS:

Related FEATURES:

**FUNCTION**

- ☐ Compound
- ☐ Domestic unit
- ☐ Mosque
- ☐ School
- ☐ Public space
- ☐ Sitting area (baraha)
- ☐ Commercial unit
- ☐ Shops/souq
- ☐ Storage
- ☐ Stable
- ☐ Workshop
- ☐ Unknown/Other

General Description

Plan / Sketch

**SIZE**

Length:

Width:

**PERIOD**

- ☐ 2009 movie rebuilding
- ☐ Late occupations (cement)
- ☐ Main occupations
- ☐ Early occupations
- ☐ Other occupations

**CONDITION**

- ☐ Excellent
- ☐ Good
- ☐ Moderate
- ☐ Poor
- ☐ Unknown

RISK ASSESSMENT

- ☐ HIGH PRIORITY
- ☐ MEDIUM PRIORITY
- ☐ LOW PRIORITY

PHOTO Numbers:

| CONSERVATION INTEREST | | |
|---|---|---|
| ☐ HIGH | ☐ MEDIUM | ☐ LOW |

Ref.: Appendix 10: Manual for Architectural recording.

| QIAH - HERITAGE | SITE: | ROOM: |
|---|---|---|
| | DATE: | SEASON: Phase 1 Season1 |

| RELATIONS | | FUNCTION | | |
|---|---|---|---|---|
| | Related STRUCTURE: | | ☐ Courtyard | ☐ Prayer room / Iwan |
| | Related ROOMS: | | ☐ Domestic unit | ☐ Mihrab |
| | Related WALLS: | | ☐ Hammam / WC | ☐ Minaret |
| | Related FEATURES: | | ☐ Storage | ☐ Sitting area (baraha) |
| | | | ☐ Kitchen | ☐ Ablution room |
| | | | ☐ Shed | ☐ Workshop |
| | | | ☐ Shelter | ☐ Unknown/Other |

| General Description | Plan / Sketch |
|---|---|
| | |

| SIZE | |
|---|---|
| | Length: |
| | Width: |

| PERIOD | | CONDITION | | RISK ASSESSMENT |
|---|---|---|---|---|
| | ☐ 2009 movie rebuilding | | ☐ Excellent | ☐ HIGH PRIORITY |
| | ☐ Late occupations (cement) | | ☐ Good | ☐ MEDIUM PRIORITY |
| | ☐ Main occupations | | ☐ Moderate | ☐ LOW PRIORITY |
| | ☐ Early occupations | | ☐ Poor | |
| | ☐ Other occupations | | ☐ Unknown | |

| | COMPOSITION | | CONDITION | DAMAGES |
|---|---|---|---|---|
| FLOOR | ☐ Anhydrite/ Gypsum<br>☐ Mud<br>☐ Soil<br>☐ Shells | ☐ Cement<br>☐ Fine cement finish<br>☐ Other<br>☐ Unknown | ☐ Excellent<br>☐ Good<br>☐ Moderate<br>☐ Poor<br>☐ Unknown | ☐ Cracks in floor surface<br>☐ Loose floor surface<br>☐ Collapsed stones<br>☐ Collapsed plaster<br>☐ Blown-in sand deposits<br>☐ Litter / bushes |
| CEILING | ☐ Round beams<br>☐ Rectangular beams<br>☐ Planks<br>☐ Bamboo | ☐ Woven mats<br>☐ Mud covering<br>☐ Unknown – not visible<br>☐ No ceiling / roof | ☐ Excellent<br>☐ Good<br>☐ Moderate<br>☐ Poor<br>☐ Unknown | ☐ Insect frass on beams<br>☐ Rot damage on beams<br>☐ Broken beams<br>☐ Partly collapsed roof<br>☐ Collapsed roof – visible on floor |
| | | | PHOTO Numbers: | |

Ref.: Appendix 10: Manual for Architectural recording.

APPENDIX 9.6 ARCHITECTURAL RECORD - Wall

| **QIAH - HERITAGE** | SITE: | | WALL: |
|---|---|---|---|
| | DATE: | SEASON: | Phase 1 Season1 |

| RELATIONS | | OPENINGS | Type: | Size: | Description: |
|---|---|---|---|---|---|
| | Related STRUCTURE: | | | | |
| | Related ROOMS: | | | | |
| | Related WALLS: | | | | |
| | Related FEATURES: | | | | |

| General Description | Plan / Sketch |
|---|---|
| | |

| SIZE | |
|---|---|
| | Length: |
| | Width: |
| | Height inside: |
| | Height outside: |

| PERIOD | | CONDITION | | RISK ASSESSMENT |
|---|---|---|---|---|
| | ☐ 2009 movie rebuilding | | ☐ Excellent | ☐ HIGH PRIORITY |
| | ☐ Late occupations (cement) | | ☐ Good | ☐ MEDIUM PRIORITY |
| | ☐ Main occupations | | ☐ Moderate | ☐ LOW PRIORITY |
| | ☐ Early occupations | | ☐ Poor | |
| | ☐ Other occupations | | ☐ Unknown | |

| COMPOSITION | Stones | Mortar | Plaster | DAMAGES | |
|---|---|---|---|---|---|
| | ☐ Beachrock AG | ☐ Mud fine grain | ☐ Anhydrite/Gypsum | | ☐ Cracks in wall |
| | ☐ Beachrock BJ | ☐ Mud coarse grain | ☐ Mud, fine grain | | ☐ Voids in wall |
| | ☐ Beachrock LO | ☐ Cement | ☐ Mud, coarse grain | | ☐ Eroded stones |
| | ☐ Gypsium BE | ☐ Not visible | ☐ Mud slurrying | | ☐ Blown out/eroded joints |
| | ☐ Dolomite BL | ☐ Unknow | ☐ Cement | | ☐ Partly collapsed |
| | ☐ Fossiliferous limestone | | ☐ Fine cement finish | | ☐ Collapsed |
| | ☐ Aeolinanite FR | | ☐ Other | | ☐ Plaster fragmented |
| | ☐ Conglomerate | | ☐ Unknown | | ☐ Detached plaster |
| | ☐ Coral | | | | ☐ Cracks in plaster |
| | ☐ Concrete blocks (old) | | | | ☐ Voids in plaster |
| | ☐ Concrete blocks (new) | | | | ☐ Plaster eroded/washed off |
| | ☐ Unknown | | | | ☐ Blow-in sand deposits |
| | Predominant: | Predominant: | Predominant: | | ☐ Graffiti |

PHOTO Numbers:

Ref.: Appendix 10: Manual for Architectural recording.

| QIAH - HERITAGE | SITE: | FEATURE: |
|---|---|---|
| | DATE: | SEASON: Phase 1 Season1 |

**RELATIONS**

Related STRUCTURE:

Related ROOMS:

Related WALLS:

Related FEATURES:

**FUNCTION**

- ☐ Pillar
- ☐ Terrace
- ☐ Terrace & pillars
- ☐ Stairs
- ☐ Fireplace/hearth
- ☐ Bench
- ☐ Basin
- ☐ Water tank
- ☐ Water well
- ☐ Mihrab
- ☐ Minbar
- ☐ Timber structure
- ☐ Portal
- ☐ Unknown/Other

General Description

**SIZE**

Length:
Width:
Height:

Plan / Sketch

**PERIOD**

- ☐ 2009 movie rebuilding
- ☐ Late occupations (cement)
- ☐ Main occupations
- ☐ Early occupations
- ☐ Other occupations

**CONDITION**

- ☐ Excellent
- ☐ Good
- ☐ Moderate
- ☐ Poor
- ☐ Unknown

**RISK ASSESSMENT**

- ☐ HIGH PRIORITY
- ☐ MEDIUM PRIORITY
- ☐ LOW PRIORITY

**COMPOSITION**

| Stones | Mortar | Plaster |
|---|---|---|
| ☐ Beachrock AG | ☐ Mud fine grain | ☐ Anhydrite/Gypsum |
| ☐ Beachrock BJ | ☐ Mud coarse grain | ☐ Mud, fine grain |
| ☐ Beachrock LO | ☐ Cement | ☐ Mud, coarse grain |
| ☐ Gypsium BE | ☐ Not visible | ☐ Mud slurrying |
| ☐ Dolomite BL | ☐ Unknow | ☐ Cement |
| ☐ Fossiliferous limestone | | ☐ Fine cement finish |
| ☐ Aeolinanite FR | | ☐ Other |
| ☐ Conglomerate | | ☐ Unknown |
| ☐ Coral | | |
| ☐ Concrete blocks (old) | | |
| ☐ Concrete blocks (new) | | |
| ☐ Unknown | | |
| Predominant: | Predominant: | Predominant: |

**DAMAGES**

- ☐ Collapsed
- ☐ Partly collapsed
- ☐ Cracks in feature
- ☐ Voids in feature
- ☐ Eroded stones
- ☐ Blown out/eroded joints
- ☐ Blow-in sand deposits
- ☐ Plaster fragmented
- ☐ Detached plaster
- ☐ Cracks in plaster
- ☐ Voids in plaster
- ☐ Plaster eroded/washed off
- ☐ Graffiti
- ☐ Litter/bushes

PHOTO Numbers:

Ref.: Appendix 10: Manual for Architectural recording.

APPENDIX 10

# Manual for Architectural Recording

## at Heritage Sites in the Zubarah Hinterland

by BERNADETA SCHÄFER
with Anne Mette Harpelund

| QIAH - HERITAGE | MANUAL for Architectural Recording |
|---|---|

## INTRODUCTION

An *Access* database provides detailed information on the building materials and the structural condition of the architecture in Al Jumail.
The database has a hierarchic composition. Four forms dedicated to structures, rooms, walls and features contain similarly structured sets of data describing spatial relations, functions, size, building period, condition, risk assessment and conservation interest of every structural element.

### STRUCTURE

| | | |
|---|---|---|
| **Relations** | | Related STRUCTURES, ROOMS, WALLS and FEATURES |
| **Function** | See appendix 1 | Compound, Domestic unit, Mosque, School, Public space, Sitting area/Majlis, Sitting area/Baraha/Dekka, Commercial unit, Shop/Souq, Storage, Stable, Workshop, Unknown/ Other |
| **Plan/ Sketch** | | Drawing produced during the survey or by detailed measurements |
| **General Description** | | Information on the form of the structure and on the spatial connections and relations of its elements (rooms and openings) to each other. Description of the ground plan of the structure and succession of the building phases. Additional comments and remarks |
| **Size** | Length, Width, Surface area | Information on the outer measurements and the area of the whole of the structure |
| **Period** | See appendix 2 | 21st century<br>20th century<br>Pre-20th century |
| **Condition** | Excellent | Complete structure, with no OR few cracks in the covering plaster |
| | Good | Structure collapsed to slight extent OR small voids and/or cracks (width under 1cm) in the stonework |
| | Moderate | Partly collapsed structure OR extensive voids and/or cracks (width over 1 cm) in the stonework; critical structural damages |
| | Poor | Extensively collapsed structure, mostly rubble |
| | Unknown | Predominantly non visible or inaccessible structures |
| **Risk Assessment** | High priority | High structures (more than 1,50m) of poor condition |
| | Medium priority | Structures of about 1,50m height, in moderate or poor condition |
| | Low priority | Stable walls and harmless rubble |
| **Conservation Interest** | High | Historical structures, clearly showing the traditional constructions and functions |
| | Medium | Historical structures, low legibility |
| | Low | Modern structures |
| **Photo numbers** | | All DNG-Photo numbers displaying the whole structure |

## ROOM

| | | |
|---|---|---|
| **Relations** | | Related STRUCTURES, ROOMS, WALLS and FEATURES |
| **Function** | See appendix 1 | Ablution room, Courtyard, Domestic unit, Hammam/WC, Kitchen, Mihrab, Minaret, Prayer room/Iwan, Shed, Shelter, Sitting area/Baraha/Dekka, Sitting area/Majlis, Storage, Workshop, Other/Unknown |
| **Plan/ Sketch** | | Drawing produced during the survey or by detailed measurements |
| **General Description** | | Information on the form of the room and on the spatial connections and relations of its elements (e.g. openings) to each other, succession of the building phases. Additional comments and remarks |
| **Size** | Length, Width, Surface area | Information on the measurements and surface area of the room |
| **Period** | See appendix 2 | 21st century<br>20th century<br>Pre-20th century |
| **Condition** | **The condition assessment concerns the general impression of the room as whole. The structural condition of the majority of the walls, floor and ceiling is taken into account** | |
| | Excellent | Complete structure, with no OR few cracks in the covering plaster |
| | Good | Structure collapsed to slight extent OR small voids and/or cracks (width under 1cm) in the stonework |
| | Moderate | Partly collapsed structure OR extensive voids and/or cracks (width over 1 cm) in the stonework; critical structural damages |
| | Poor | Extensively collapsed structure, mostly rubble |
| | Unknown | Predominantly non visible or inaccessible structures |
| **Risk Assessment** | High priority | High structures (more than 1,50m) of poor condition |
| | Medium priority | Structures of about 1,50m height, in moderate or poor condition |
| | Low priority | Stable walls and harmless rubble |
| **Floor composition** | See Appendix 3 | Anhydrite, Lime, Mud, Soil, Shells, Cement, Fine cement finish, Other/ Unknown |
| **Floor condition** | **Applies only to floors with screed topping (anhydrite, lime or cement). Floors made of shells, mud or soil are always ranged as "good"** | |
| | Excellent | No OR few superficial cracks in the screed topping |
| | Good | Cracks in the plaster, small, flat voids in the screed topping |

| | | | |
|---|---|---|---|
| | Moderate | Extensive voids and cracks in the screed topping, thick fragments of screed missing | |
| | Poor | Screed topping missing on extensive area of the floor, deep voids in the floor | |
| | Unknown | Non visible | |
| **Floor damages** | Cracks in floor surface | Cracks in the screed topping |  Al Jumail, S40 - mosque. Cracks on the steps leading to the courtyard of the mosque |
| | Voids in floor surface | Parts of the screed topping are missing | |
| | Loose floor surface | Screed topping is detached, shows voids, it is easy to remove screed layers without tools | No Photo |
| | Collapsed stones | Stones fallen from the walls of the room, covering the floor surface |  Al Jumail, S40 - mosque. Fragments of plaster, stones, blown-in sand deposits and litter visible on the floor |
| | Collapsed plaster | Detached plaster fallen from the walls of the room, covering the floor | |
| | Blown-in sand deposits | Sand blown in by the wind, covering the floor | |
| | Litter/bushes | Litter deposits or litter blown in by the wind; plants growing, damaging floor surface | |
| **Ceiling composition** | Round beams, Rectangular beams, Planks, Bamboo, Woven mats, Mud covering, Unknown - not visible, No ceiling/roof | The roofs are usually composed of round, rectangular beams or planks supporting splitted bamboo stems and woven mats. The top covering consists of mud layer and sometimes small gravel. |  Al Jumail, S40, Roof of round beams, bamboo, woven mats and mud covering |

| | | |
|---|---|---|
| **Ceiling condition** | Excellent | Covering complete, no structural damage |
| | Good | Mud covering complete, little insect damage on the beams |
| | Moderate | Damage by insects and/or fungi, ceiling strongly deformed |
| | Poor | Extensive damage by insects and/or fungi, ceiling partly collapsed |
| | Unknown | Construction not accessible for investigation |

## WALL

| | | |
|---|---|---|
| **Relations** | | Related STRUCTURES, ROOMS, WALLS and FEATURES |
| **Openings** | Type, Size, Description | Type: Door, window, ventilation opening<br>Size: Width, Height<br>Description: Lintel construction, window frame, condition, comments |
| **Plan/ Sketch** | | Drawing produced during survey or by detailed measurements |
| **General Description** | | Information on the spatial arrangement of the openings. Indication of the succession of the building phases. Comments and remarks |
| **Size** | Length, Width, Height<br>Height | Information on the maximal measurements of the wall. As the height of the wall may differ in the related rooms or between the room and the façade, both values have to be given |
| **Period** | See appendix 2 | 21$^{st}$ century<br>20$^{th}$ century<br>Pre-20$^{th}$ century |
| **Condition** | Excellent | Complete, with no OR few cracks in the covering plaster |
| | Good | Collapsed to slight extent OR small voids and/or cracks (width under 1cm) in the stonework |
| | Moderate | Partly collapsed structure OR extensive voids and/or cracks (width over 1 cm) in the stonework; critical structural damages |
| | Poor | Extensively collapsed structure, mostly rubble |
| | Unknown | Predominantly non visible or inaccessible structures |
| **Risk Assessment** | High priority | High structures (more than 1,50m) of poor condition |
| | Medium priority | Structures of about 1,50m height, in moderate or poor condition |
| | Low priority | Stable walls and harmless rubble |

| | | |
|---|---|---|
| **Damages** | Cracks in wall | Cracks, reaching deep inside of the stonework´s structure |
| | Voids in wall | Stones broken off the wall, leaving voids in the stonework |
| | Eroded stones | Surface of stones eroded by the influence of wind, salts and moisture |
| | Blown out/ eroded joints | Stones in place, mortar of the joints eroded by the influence of wind, salts and moisture |
| | Partly collapsed | Wall partly collapsed, still standing parts allow the insight in the construction and the identification of the openings |
| | Collapsed | Wall entirely collapsed, remains recognizable as rubble |
| | Plaster fragmented | Deep cracks in plaster |
| | Detached plaster | Plaster loosened from the wall, easy to remove without tools |
| | Cracks in plaster | Superficial, "hair-thin" cracks in plaster, no structural damage |
| | Voids in plaster | Fragments of plaster missing, fallen off the wall |
| | Plaster eroded/ washed off | Layers of plaster eroded by the influence of wind, salts and moisture |
| | Blown-in sand deposits | Sand deposits in the eroded joints and voids of the stonework |
| | Graffiti | Ornaments or text scratched or painted on plaster |
| **Photo numbers** | | All DNG-Photo # displaying the wall |

## FEATURE

| | | |
|---|---|---|
| **Relations** | | Related STRUCTURES, ROOMS, WALLS and FEATURES |
| **Function** | See appendix 1 | Basin, Bench, Fireplace/Hearth, Mihrab, Minbar, Niche/Shelves, Pillar, Terrace, Terrace&Pillars, Timber structure, Portal, Staircase or Steps, Water tank, Water well, Other/Unknown |
| **Plan/ Sketch** | | Drawing produced during a survey or by detailed measurements |
| **General Description** | | Information on the form of the feature, indication of building phases, comment and remarks |
| **Size** | Length, Width, Height | Information on the outer measurements of the feature |

| | | |
|---|---|---|
| **Period** | See appendix 2 | 21st century |
| | | 20th century |
| | | Pre-20th century |
| **Condition** | Excellent | Complete, with no OR few cracks in the covering plaster |
| | Good | Collapsed to slight extent OR small voids and/or cracks (width under 1cm) in the stonework |
| | Moderate | Partly collapsed structure OR extensive voids and/or cracks (width over 1 cm) in the stonework; critical structural damages |
| | Poor | Extensively collapsed structure, mostly rubble |
| | Unknown | Predominantly non visible or inaccessible structures |
| **Risk Assessment** | High priority | High structures of poor condition |
| | Medium priority | Structures of about 1,50m height, in moderate or poor condition |
| | Low priority | Stable walls and harmless rubble |
| **Damages** | Cracks in feature | Cracks, reaching deep inside of the stonework |
| | Voids in feature | Stones broken off the wall, leaving voids in the stonework |
| | Eroded stones | Surface of stones eroded by the influence of wind, salts and moisture |
| | Blown out/eroded joints | Stones in place, mortar of the joints eroded by the influence of wind, salts and moisture |
| | Partly collapsed | Feature partly collapsed, still standing parts allow the insight in the construction and the identification of the openings |
| | Collapsed | Feature entirely collapsed, remains recognizable only as rubble |
| | Plaster fragmented | Deep cracks in plaster |
| | Detached plaster | Plaster loosened from the underground, easy to remove without tools |
| | Cracks in plaster | Superficial, "hair-thin" cracks in plaster, no structural damage |
| | Voids in plaster | Fragments of plaster missing, fallen off the underground |
| | Plaster eroded/ washed off | Layers of plaster eroded by the influence of wind, salts and moisture |
| | Blown-in sand deposits | Sand deposits in the eroded joints and voids of the stonework or sand deposits inside of the feature |
| **Photo numbers** | | All DNG-Photo # displaying the feature |

# Appendix 1 - FUNCTIONS

## Sturctures, Rooms

| | | |
|---|---|---|
| **Ablution room** | Room for ritual purification, adjusted or located close to the mosque and provided with water (well, tank, water tap) and a washing basins |  **JU_S40** |
| **Commercial unit** | Workshop, production building or shop, working space | No Photo |
| **Compound** | Series of buildings interconnected and/or adjusted to each other, arranged around a courtyard |  **JU_S58** |
| **Courtyard** | Space inside of a building or compound, surrounded by walls, without a covering | Photo: See **Compound** or **School** |
| **Domestic unit** | Compound or single building for dwelling purpose | Photo: See **Compound** |
| **Hammam / WC** | Restroom; mostly a part of a domestic unit separated by a wall, provided with small basin and drainage opening |  **JU_S15** |
| **Kitchen** | Room for food preparation | No Photo |

| | | |
|---|---|---|
| **Mosque** | Building of worship for followers of Islam |  JU_S40 |
| **Minaret** | Distinctive architectural feature of mosques, generally a tall spire, usually free standing and taller than any associated structure. Minarets are used for the call to prayer | |
| **Mihrab** | Small room in the wall of a mosque that indicates the qibla - the direction of the Kaaba in Mecca and hence the direction that Muslims should face when praying |  JU_S40 |
| **Prayer room / Iwan** | Rectangular hall or space in the mosque, walled on three sides, with one end entirely open, used for prayer. The prayer room is oriented to the direction on Kaaba in Mecca by the mihrab |  JU_S40 |
| **Public space** | Open space (square or street), outside of the private domestic units | Photo: See **Minaret / Mosque** |
| **School** | Structure explicitly dedicated for educational purposes provided with classrooms and teachers room |  JU_S64 |
| **Shed** | Simple, one storey building, may be used as storage or workshop | No Photo |
| **Shelter** | Simple structure or building that provides cover | No Photo |
| **Shops/Souq** | Shop or assembly of shops (souq) | No Photo |

| | | |
|---|---|---|
| **Sitting area: Majlis** | Public / semi-public gathering space in form of a free standing, single-room building. Majlis lay in a free, public space and are not adjusted to other buildings or compounds. The Majlis appear mostly as ensemble along with a Baraha/Dekka |  **JU_S60** |
| **Sitting area: Baraha/Dekka** | Public / semi-public gathering space in form of a free standing flat platform. Baraha/ Dekka lay in a free, public space and are not adjusted to other buildings or compounds. Sometimes the Majlis has an open terrace adjusted to it. In this case there is no other Baraha/Dekka that would go with this kind of Majlis |  **JU_S61** |
| **Stable** | Building for keeping of livestock | No Photo |
| **Storage** | Building for storage of goods | No Photo |
| **Workshop** | Room or building that provides space and tools for production of goods | No Photo |

## Features

| | | |
|---|---|---|
| **Basin** | Kind of sink or bowl to contain water for cleaning hands and other minor ablutions |   **JU_S40** |
| **Bench** | Small structure for sitting |  **JU_S58** |

| | | |
|---|---|---|
| **Fireplace / hearth** | Structure designed to contain a fire for heating and for cooking |  **JU_S50** |
| **Mihrab** | Niche in the wall of a mosque that indicates the qibla - the direction of the Kaaba in and hence the direction that Muslims should face when praying |  **JU_S40** |
| **Minbar** | Pulpit in the mosque close to the mihrab, where the imam (prayer leader) stands to deliver sermons or where the speaker sits and lectures |  **JU_S40** |
| **Niche / Shelves** | Setback in the wall, in connection with the window opening or providing space for shelves |  **JU_S58** |
| **Terrace** | Raised flat platform connected to a building |  **JU_S64** |
| **Pillar** | Free standing feature supporting a covering, square in the cross-section | |
| **Terrace & Pillars** | Raised flat platform connected to a building, pillars with covering | |

| | | |
|---|---|---|
| **Portal** | Representative doorway |  **JU_S40** |
| **Staircase or steps** | Internal or external stairs |  **JU_S40** |
| **Timber structure** | Ruined timber shelters found in the courtyards of the compounds | No Photo |
| **Water tank** | Building or container constructed for water retention |  **JU_S26** |
| **Water well** | Artificial excavation, hole or structure for the purpose of withdrawing water | Photo: See **Ablutory room** |

## Appendix 2 - PERIODS

21st century

Constructions erected for a movie set in 2009 – walls of stone or cement blocks, mud/earth mortar of coarse grain and high amount of gravel, covered with mud slurry and/or shoddy plaster. Very often the proportion of mortar exceeds the proportion of stones in the stonework. Some parts of the structures may consist of provisional constructions made of wood, textile tissue and gypsum - e.g. portals or shelves.


Al Jumail,S42, courtyard walls erected in 2009; the gate made of textile and gypsum plaster

20th century

Constructions characterized by use of cement as mortar and/or plaster, walls mostly covered with additional anhydrite plaster finish, sometimes also with mud slurry.

Two different modes of cement use:

- Cement used as mortar AND plaster for constructions made of cement blocks or for stone masonry in buildings of particular use - the mosque, the school and some of the water tanks.
- Cement used ONLY as plaster. The walls being constructed of stones and mud mortar, the wall faces are consolidated by the layer of cement plastering. This kind of construction applies for ordinary domestic buildings. Courtyard walls are covered with cement OR lime based renders


Al Jumail, mosque (S40). Masonry of cement blocks and stonework covered by cement plastering (left); the ablution room´s wall has an additional layer of anhydrite finish (right)


Al Jumail, S54, stonework with mud mortar and cement plastering. Anhydrite plaster finish on the façades, no anhydrite finish on the courtyard wall (right)

Pre-20th century

Constructions built of stones and mud mortar, extensively ruined


Al Jumail, compounds in the northern part of the village. Ruined walls made of stone and mud mortar

## Appendix 3 - BUILDING MATERIALS

### Stones

**Beachrock AG**

*Colour:* White to beige
*Solidity*: Very friable/brittle, loos components
*Characteristics*: Fine grained, high content of shells and gastropods, rough surface


White stones in the picture are Beachrock AG

**Beachrock BJ**

*Colour*: Grey to light reddish
*Solidity*: Soft to medium hard
*Characteristics*: Recognizable stratification - gastropods and fine-grained sandy matrix, uniform ingredients, rough surface


**Beachrock LO**

*Colour*: Reddish to brown, grey
*Solidity:* Medium to very hard
*Characteristics:* Rough surface, numerous cavities (holes), few gastropods and shells


**Gypsum BE**

*Colour*: Yellow grey to white or bright grey
*Solidity*: Soft to medium hard (scratchable with fingernail)
*Characteristics*: Fine grained, no shells or gastropods, little holes, recognizable stratification and horizontal splits

**Dolomite BL**

*Colour*: Beige, yellowish, reddish, bluish grey
*Solidity*: Very hard
*Characteristics*: No shells or gastropods, very fine matrix, fine and polish surface, larger pieces with holes


**Fossiliferous limestone**

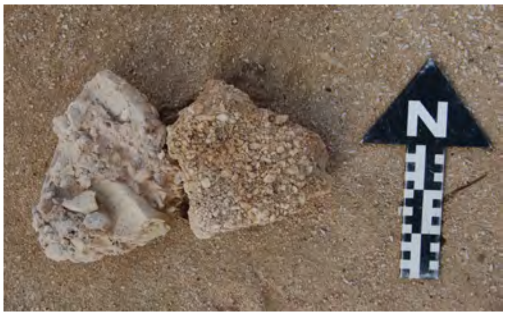
*Colour:* White to bright beige
*Solidity*: Hard
*Characteristics*: A limestone that contains obvious fossils - normally shells, cavities


**Aeolianite FR**

*Colour*: Beige
*Solidity*: Fairly hard
*Characteristics*: Medium grained, even surface, no shells or gastropods, homogenous, looks similar to sandstone

**Conglomerate**

*Colour*: Beige, grey
*Solidity*: Very hard
*Characteristics*: Mix of dolomite fragments and shells, extremely rough surface




**Coral**

*Colour:* Brownish
*Solidity:* Hard
*Characteristics:* very rough surface, sharp edges, small cavities of organic origin

| | | |
|---|---|---|
| **Concrete Block (old)** | *Colour:* Brown, grey<br>*Solidity:* Two qualities: hard and soft (falls apart when touched)<br>*Characteristics:* Both types with a high proportion of small shells. Size: 20/20/40 cm, walls of about 3 cm thickness surround two square hollow spaces |  |
| **Concrete Block (new)** | *Colour:* Grey-blue<br>*Solidity*: Very hard<br>*Characteristics:* No shells, round aggregate grains, porous. Size: 20/20/40 cm, walls of about 3 cm thickness surround two square hollow spaces |  |

## Mortars

| | | |
|---|---|---|
| **Mud, Fine Grain** | *Colour:* Light brown to brown<br>*Solidity:* Very soft<br>*Characteristics:* Fine, extremely brittle and susceptible to wind erosion, joins stones in the cores of historic walls of stone masonry. |  |
| **Mud, Coarse Grain** | *Colour:* Brown<br>*Solidity:* Soft<br>*Characteristics:* High proportion of coarse aggregate, size reaching small gravel. In the stonework the proportion of the mortar often exceeds the proportion of stones |  |

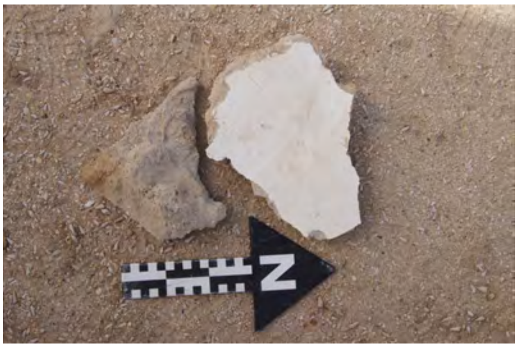
**Cement**

*Colour:* Grey, bluish-grey
*Solidity:* Very hard
*Characteristics:* Very fine aggregate, depending on the application technique smooth or rough surface


## Plasters (Renders)

**Anhydrite**

*Colour:* White
*Solidity:* Soft
*Characteristics:* Fine, smooth surface, often applied as finish layer to cement plaster




**Mud, Fine Grain**

*Colour:* Light Brown
*Solidity:* Medium
*Characteristics:* Relatively fine, fairly rough surface; mostly found on the wall faces of the buildings erected in 2009

Al Jumail, courtyard walls in the village erected partly in 2009. Left: top of the wall made of stones with earth mortar, no plastering at all. Right: the fine, thin layer of mud plaster covering the rounded wall.

**Mud Slurrying**

*Colour:* Brown
*Solidity:* Medium
*Characteristics:* Thin layer, applied like paint to the white anhydrite or cement plasters

**Lime**

*Color:* Yellow grey
*Solidity:* Hard
*Characteristics:* Loose packing of aggregate grains stabilized by calcite cement and pores in between the matrix-forming particles. The pores have about the same size as the matrix particles and add up to 40 – 45 volume percent porosity. Often applied to the courtyard walls

**Cement**

*Colour:* Grey
*Solidity:* Very Hard
*Characteristics:* Fairly rough surface, very often scratched (wavy lines) to increase the support for the following finish layer

**JU_S58**

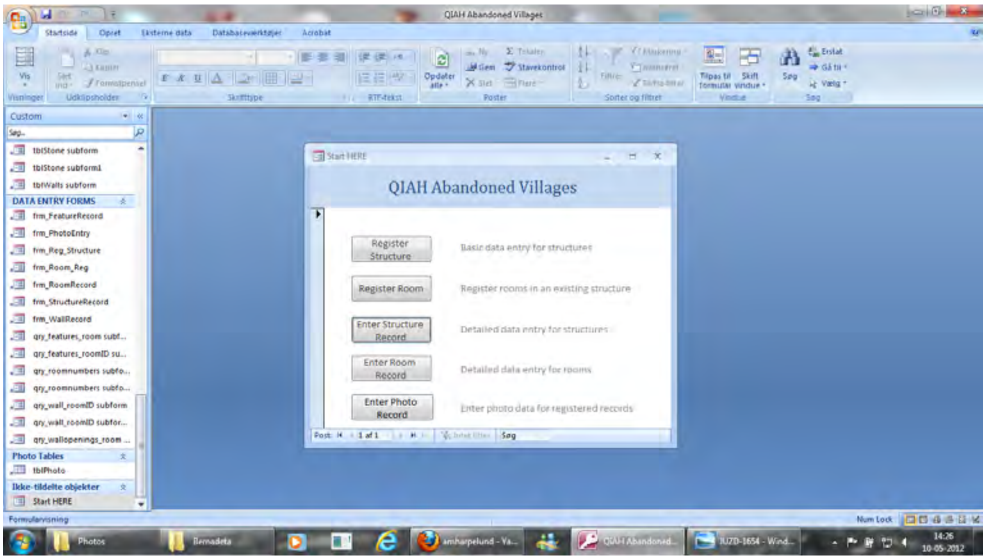
**Fine Cement Finish**

*Colour:* Grey to dark grey
*Solidity:* Very Hard
*Characteristics:* Very fine, polished, smooth surface, applied to lime or cement plaster

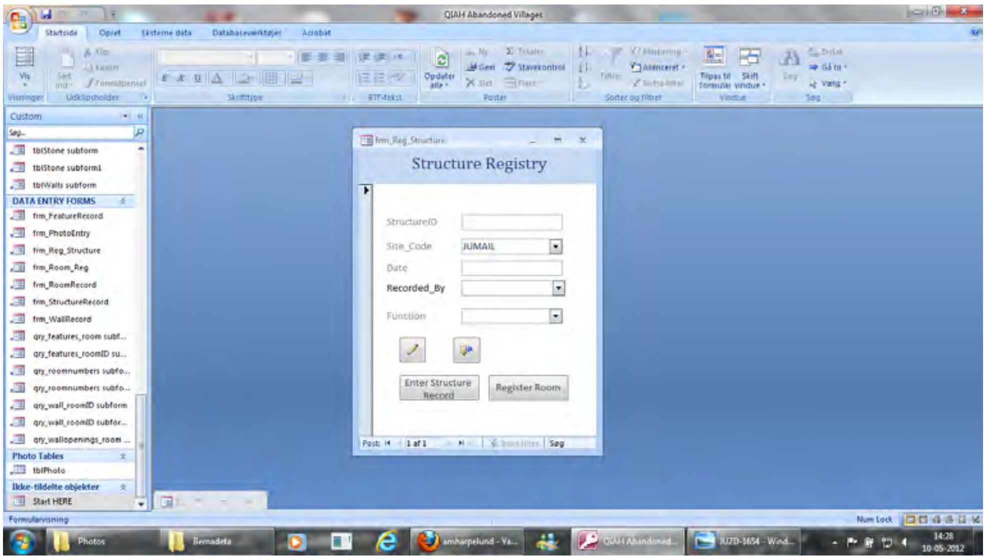
**JU_S40**

# SCREEN SHOTS of INVENTORY DATABASE for ARCHITECTURAL RECORDING

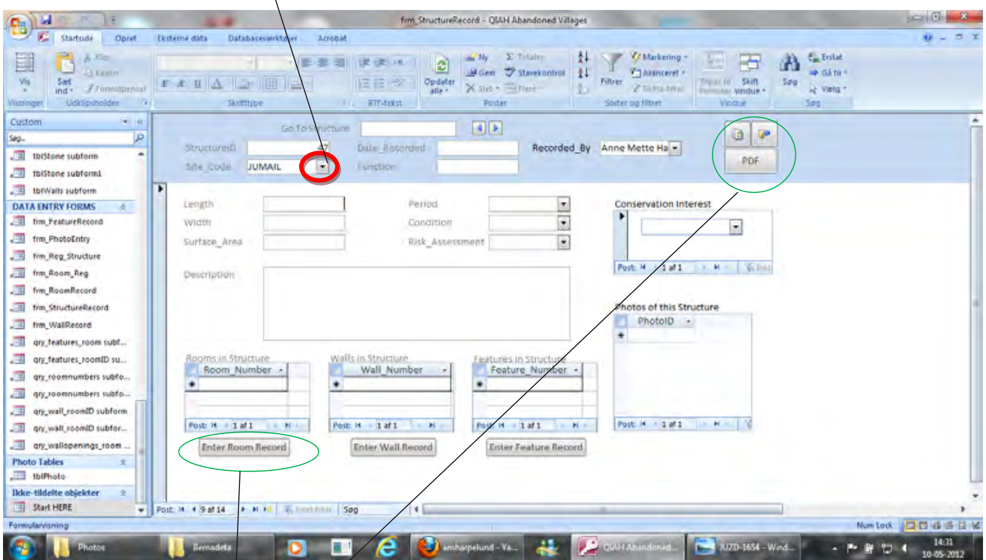
The start when you enter the database.




Structure registry. Just the basic information.



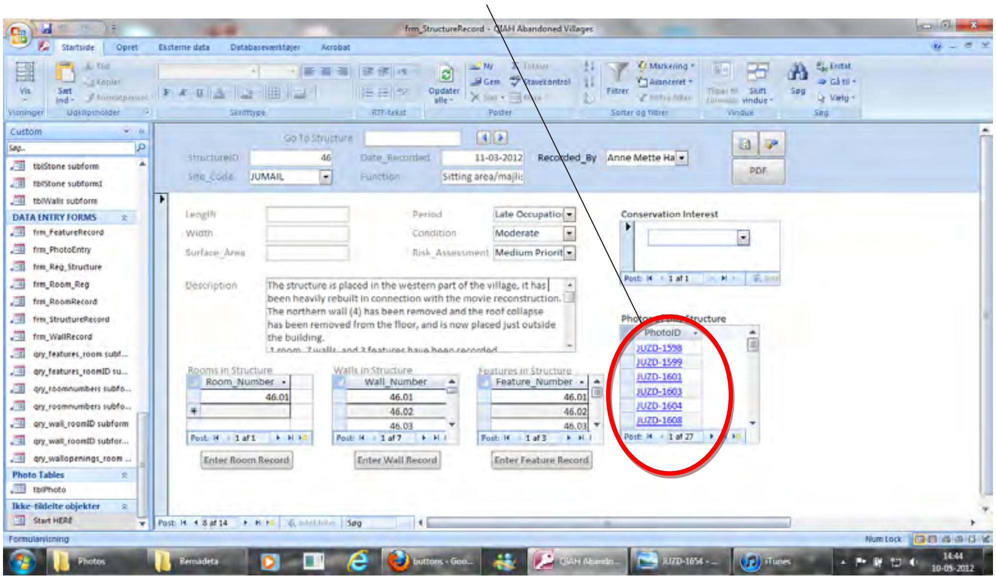

Structure record, with no information. The grey boxes with a small black arrow pointing down are scroll downs with different options.



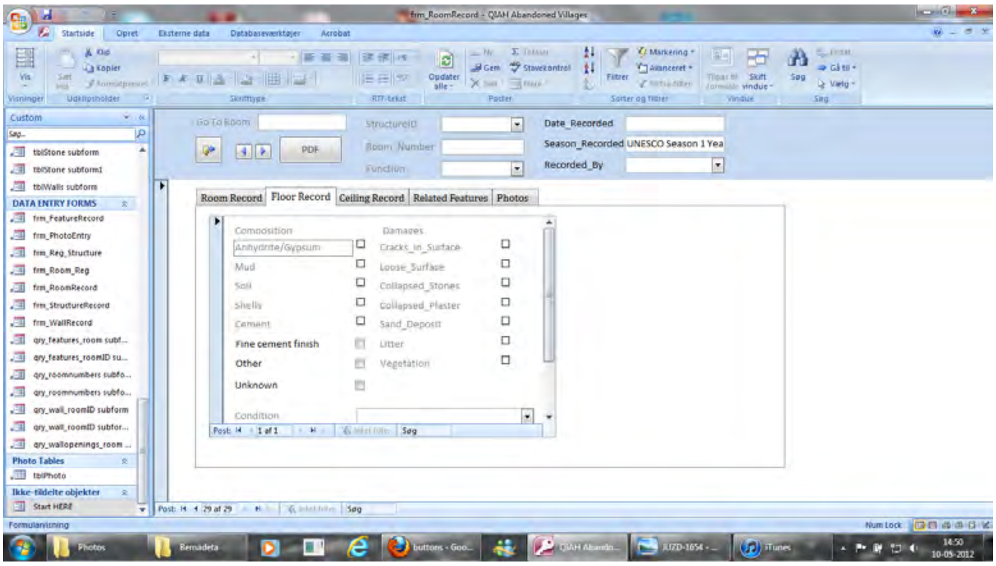

The grey 'things' such as 'Enter Room Record', 'PDF' etc., are buttons leading you to the next step, or showing the pdf file, refresh the page etc.

# SCREEN SHOTS of INVENTORY DATABASE for ARCHITECTURAL RECORDING

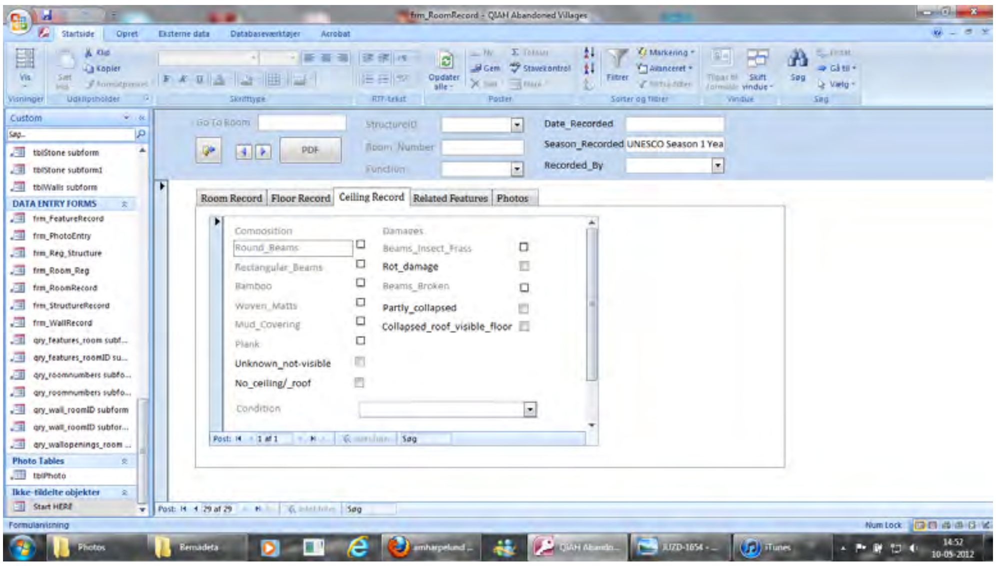
Structure record, example. You can click on the blue links and see the photos




Room record, floor. No information

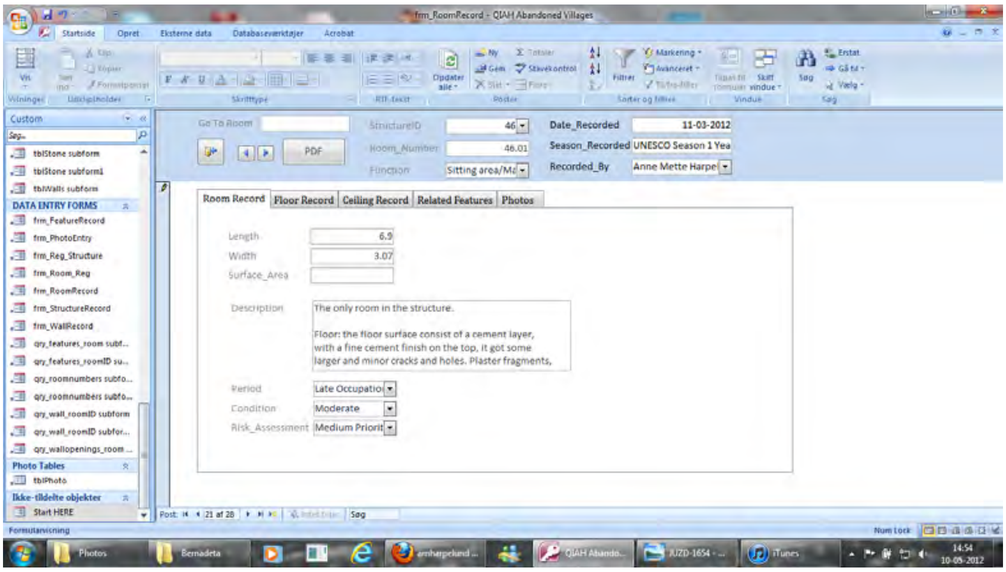



Room record, ceiling. No information.

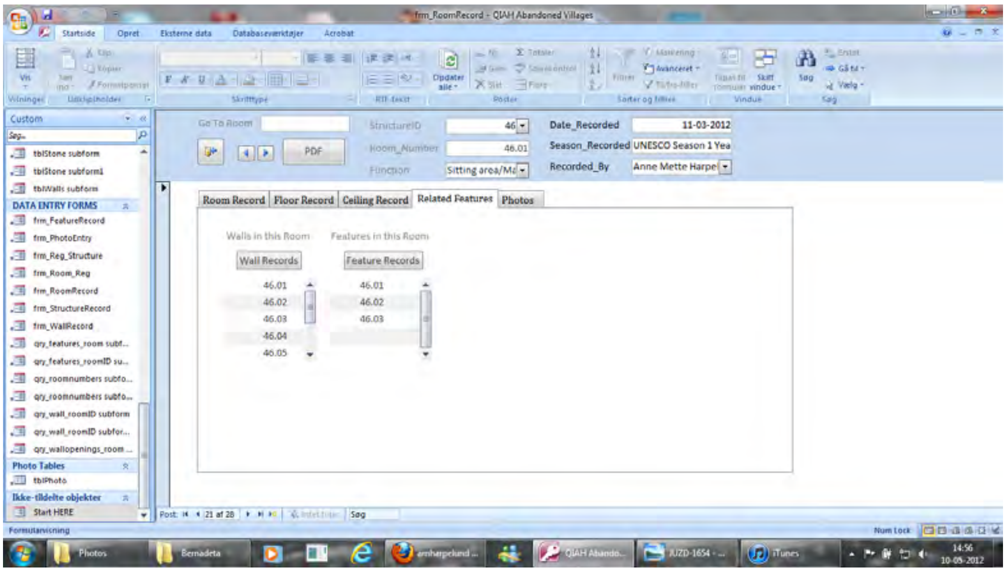


# SCREEN SHOTS of INVENTORY DATABASE for ARCHITECTURAL RECORDING

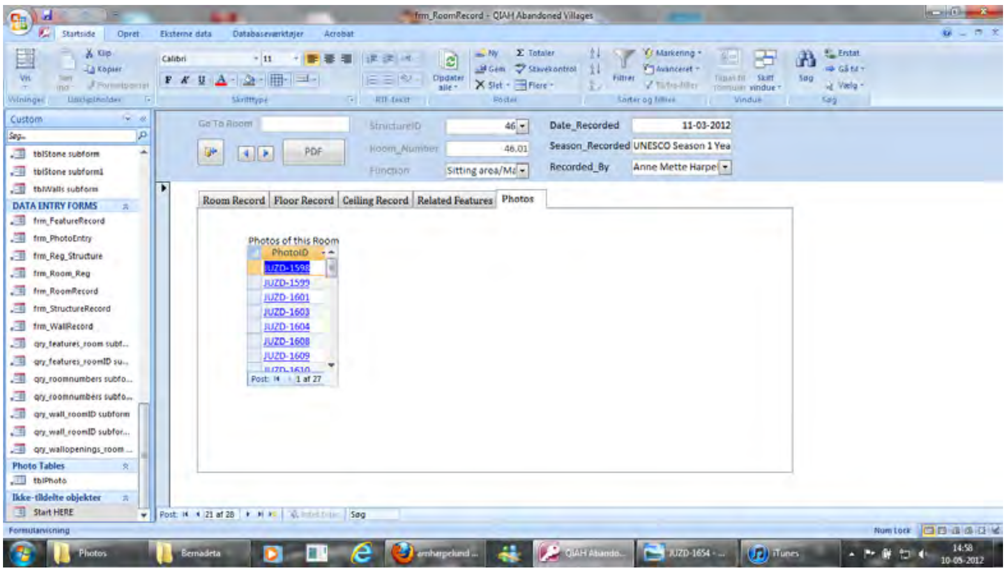
Room record, example.




Room record, related features, example.




Room record, photos, example.



# SCREEN SHOTS of INVENTORY DATABASE for ARCHITECTURAL RECORDING

Relations.

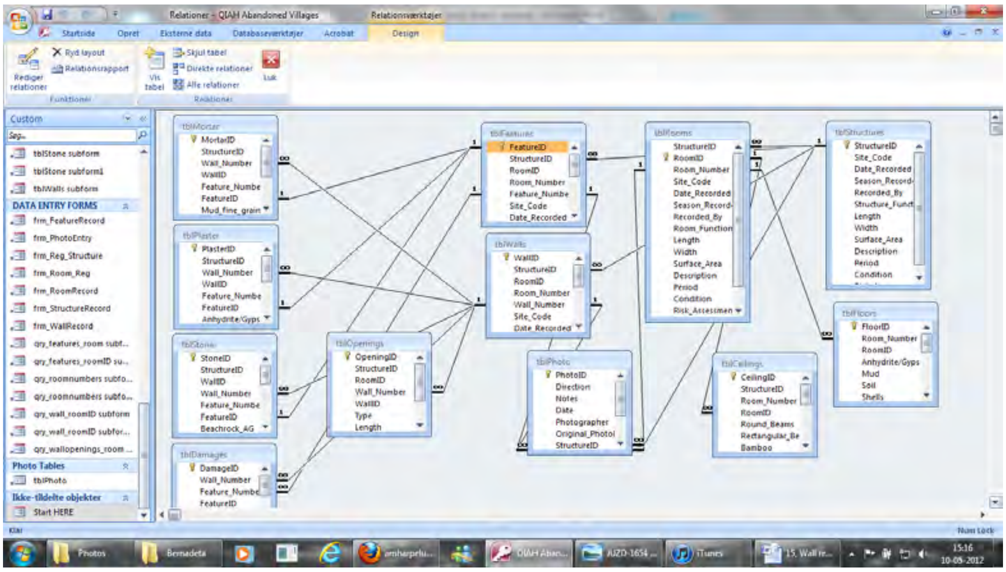
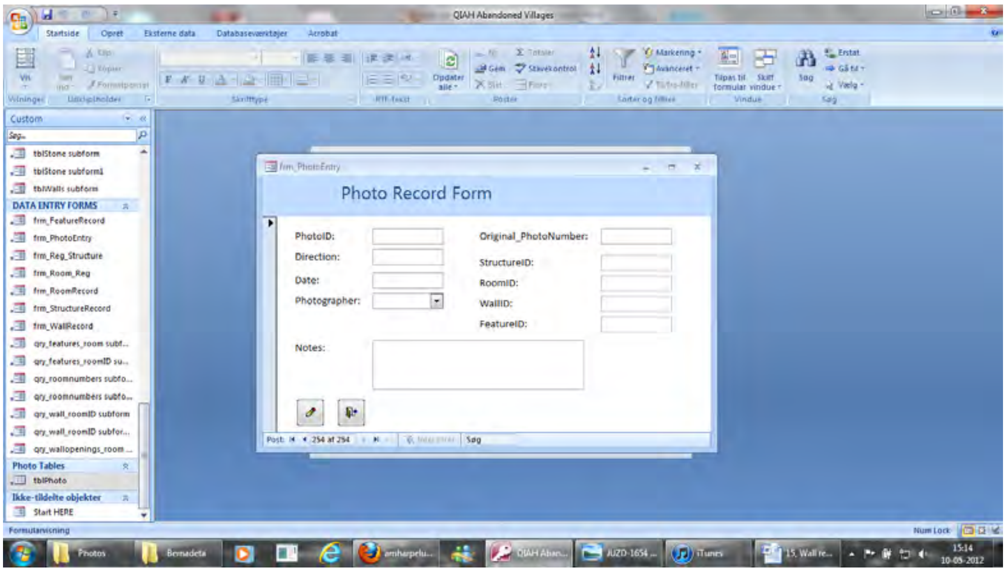


Photo record.



# APPENDIX 11

# MANUAL FOR TOURISTIC ASSESSMENT
## OF HERITAGE SITES IN THE BUFFER ZONE & THE AL ZUBARAH HINTERLAND

by BENJAMIN FABRE

# Manual for the Touristic Assessment of Heritage Sites in NW Qatar

**ASSESSMENT OBJECTIVE:** Collect information about heritage sites in order to assess their touristic potential.
The QIAH Project has already surveyed the entire region in 2012. The data collected is mostly archaeological and this new documentation intends to expand on the existing record by adding a series of indicators measuring the inherent value of each site from a touristic perspective. These new sets of indicators are divided into 2 main categories:

- Cultural and Environmental Landscape
- Infrastructural Capacities

In order to measure the touristic potential for a given site, all indicators are attributed a specific value according to their importance. Combining the recorded values will set an overall score for each site.

**COLLECTION OF INFORMATION:** The documentation sheet is divided into 4 sections:

- Site Identification details (predefined indicators)
- Main Category 1: Landscape
- Main Category 2: Infrastructure
- Future Work Proposal (optional)
-

**SITE IDENTIFICATION**

(all these indicators have been defined by the QIAH Regional Survey 2012)

- QNHER # Number assigned to each site in Qatar, *Qatar National Heritage and Environment Record*
- Site Name Informal name the site is referred to by the local population - if known
- Site Period Defined by the regional survey (Neolithic, Early Islamic, 18$^{th}$ century, etc)
- Site Type Defined by the regional survey (Settlements, water source, agricultural field, etc)
- Related sites Sites Located in the same vicinity and as well as contemporary

**LANDSCAPE INTEGRITY ASSESSMENT**

**<u>CULTURAL Landscape</u>**

**Architectural remains/ruins**

- High: standing ruins with occasional complete structural remains
- Med: visible architecture amongst ruins
- Low: very limited and unattractive visible remains

**Archaeological activity**

- H: the site is being investigated or has been comprehensively documented
- M: the site has partly been researched (excavation, survey, geology)
- L: the site has never been explored

**<u>ENVIRONMENTAL Landscape</u>**

**Vegetation**

- H: presence of a number of trees and/or mangrove and/or grass
- M: scarce presence of trees and/or mangrove and/or grass
- L: dry desert with disseminated low bushes only

**Wildlife**

- H: repeated sightings of multiple animals (e.g. multiple bird, wild mammal species OR large flocks OR colorful insects)
- M: occasional presence of some visually interesting animal species (see the above)
- L: rare occurrence of <u>visible</u> animal presence

**Nearby Intrusive Structure**

- H: No structure visible in the immediate vicinity of the site
- M: Very limited structures visible in the vicinity of the site
- L: Presence of large structures in the direct vicinity of the site

**Site Pollution**

- H: No visible pollution in the immediate vicinity of the site
- M: Presence of trash within the site
- L: Continuous overflow of large amount of trash within the site vicinity

## INFRASTRUCTURE ASSESSMENT

**Traditional Structure**
- H: Presence of traditional structure that could potentially be re-used
- M: Presence of traditional structure but badly preserved or inappropriate for re-use
- L: No presence of traditional structure

**Modern Structure**
- H: No modern structures but space available to accommodate new structures
- M: Presence of modern structure and space available to accommodate new structures
- L: No structure and very limited space for any new constructions

**Accessibility**
- H: Direct road access to the site
- M: Track access under 15 mins drive from the main road
- L: No track access to the site or over 15 mins drive from the main road

**Parking**
- H: Presence of a parking space
- M: No parking but space to accommodate a parking place
- L: Limited or no space available to accommodate a parking place

**Guard's cabin**
- H: Opportunity for the re-use of a traditional structure to put up a housing for the guard
- M: No traditional structure available for re-use but space to put up a modern or traditional structure
- L: Limited or no space available for any structure that could be used as guard's office/housing

**Toilets**
- H: Toilets available on the site
- M: No toilets available but opportunity to re-use a traditional structure for toilet purpose
- L: Limited or no toilet space available or new construction opportunity only

**Shelters**
- H: Presence of features (either natural or traditional building) that could be re-used as shelters to sit/rest/picnic
- M: Limited features available for re-use but space to put up new features
- L: Very limited space available for any feature that could be used as shelters

**Walking path/hike track**
- H: Presence of a trail/path in the site and/or connecting the site to other sites in the vicinity
- M: No trail/path available for re-use but space to put up a new trail/path
- L: Very limited space available to put up any trail/path

**Waste**
- H: Presence of garbage cans on the site and of a nearby skip
- M: No garbage cans but presence of a nearby skip
- L: No garbage cans and no skip available in the site vicinity

## PROPOSITION FOR FUTURE HERITAGE WORK

(optional)

| | | |
|---|---|---|
| QNHER # | Site Name | Site Type |
| Related sites | Site Period | Site Condition |

General description:

Re-Use with Experimental archaeology:

| **LANDSCAPE INTEGRITY** | | H - M - L | Value | Comments | **OVERALL** |
|---|---|---|---|---|---|
| CULTURAL Landscape | Architectural remains/ruins | | | | |
| | Archaeological/research activity | | | | |
| NATURAL Landscape | Vegetation | | | | |
| | Wildlife | | | | |
| | Nearby Intrusive structure | | | | |
| | Site Pollution | | | | |

| **INFRASTRUCTURE** | H – M – L | Value | Comments | **OVERALL** |
|---|---|---|---|---|
| Traditional structure | | | | |
| Modern Structure | | | | |
| Accessibility | | | | |
| Parking | | | | |
| Guard's cabin | | | | |
| Toilet | | | | |
| Shelters | | | | |
| Walking path/hike track | | | | |
| Waste Management | | | | |

| **TOURISTIC POTENTIAL** | |
|---|---|

# APPENDIX 12

# CONSERVATION SCHEMES

## FOR ARCHITECTURAL REMAINS AT AL ZUBARAH / QATAR

by MORITZ KINZEL

December 2012

**APPENDIX 12 Conservation Schemes**

12.1 Town wall (segments exposed in 1980s)

12.2 Town wall segments exposed by QIAH

12.3 Fortified Compound QMA 4

12.4 Palace EPO4 (in prep.)

# APP.12.1 CONSERVATION SCHEME TOWN WALL
## for segments exposed in 1980s

State of Conservation

Wall segment 8/9 11/2009

Wall segment 8/9 02/2012

The outer town wall of Al Zubarah was excavated partly in the 1980s. The remains were consolidated then and capped with a flat cement layer. Over the past thirty years huge amounts of soil and sand deposit had accumulated on the exterior and the exposed wall segments were heavily effected by the harsh environmental conditions. When the QIAH-Project was initiated in 2009 it was decided to remove the accumulated deposits to make the town wall more visual for visitors and to gain a better understanding of its structural conditions. Based on the initial record of the state of conservation the conservation concept for the town wall was developed.

# APP.12.1 CONSERVATION SCHEME TOWN WALL
## for segments exposed in 1980s

State of Conservation



State of conservation
left: during 1980s excavation; right: in Nov. 2009

## CONSOLIDATION OF EXTERIOR/OUTER WALL SEGMENT

1. **Documentation** of State of Conservation / **Planning** of Measures
2. **Consolidation** outer wall face (Fiche 3 ; Fiche 3.1)
    a) Re-placement of damaged wall stones
    b) Inserting new wall stones and new socle zone: up right standing conglomerate (La) stone slab and one course dolomite (Bl) to avoid damages caused by salt crystallisation (Fiche 3.2).

3. **Re-pointing** of joints (Fiche 3.3)

4. **Take-off of cement capping** (1980s) (Fiche 3.1)

5. **Re-shaping of wall tops** with additional wall stones (case to case basis) (Fiche 3.3 / 3.4)

6. **Re-plastering** of the "outer" wall segment: a) Wall faces with "hand tooling" (Fiche 3.5.2); b) Wall top with "Rough" surface (Fiche 3.5.3).

7. **Sharp edge line** defines wall face and wall top. "Double" line showing thickness of plaster (Fiche 3.5).

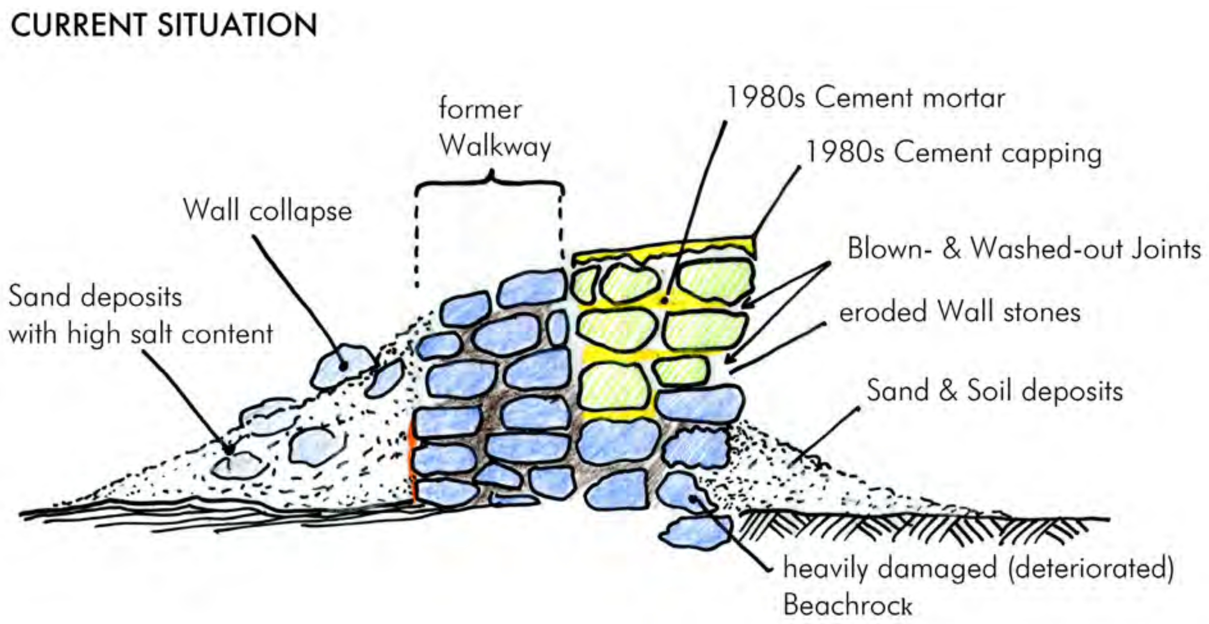
8. Not exposed walkways should **be kept uncovered or will be covered again** with a soil/sand layer after works at outer wall segment are finalised (Fiche 5; 5.1, and 5.2).

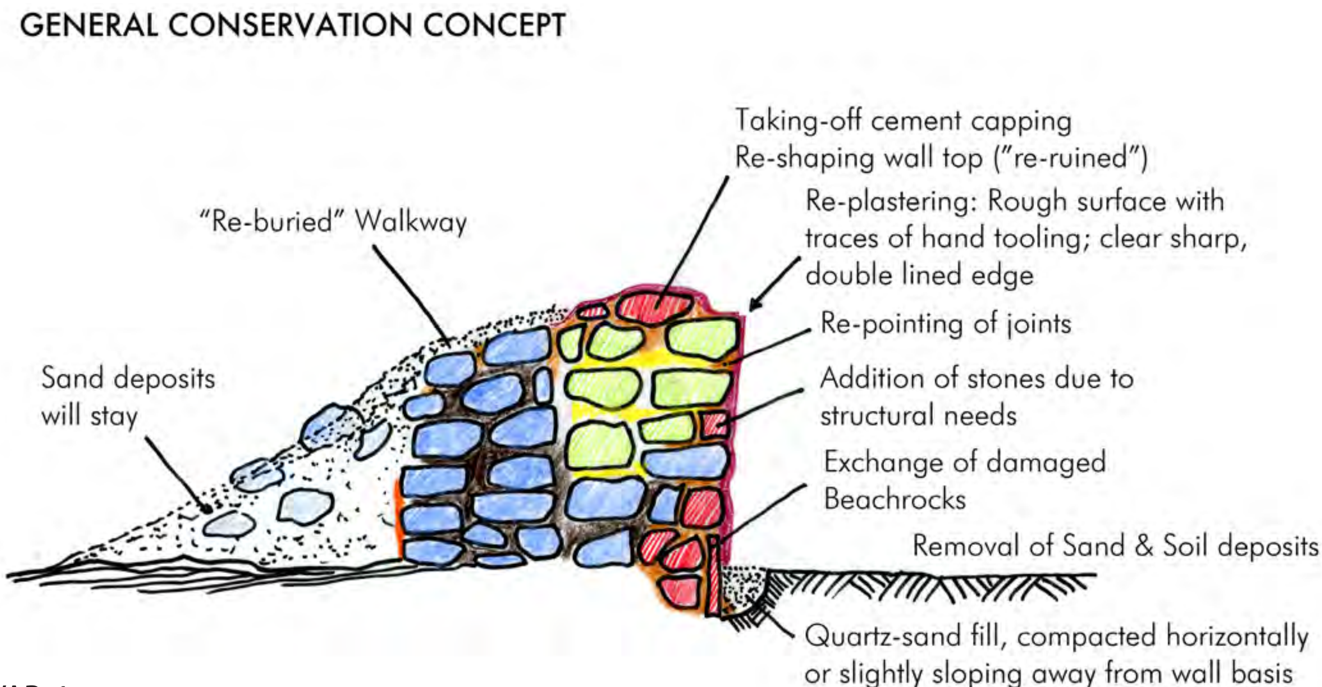
9. Produce **report** on executed measures to be stored with the Inventory data base.

10. Regular **monitoring** after the measure take place to initiate repairs when needed.

# APP.12.1 CONSERVATION SCHEME TOWN WALL
for segments exposed in 1980s

GENERAL CONSERVATION CONCEPT




VAR. 1

# APP.12.1 CONSERVATION SCHEME TOWN WALL
## for segments exposed in 1980s

Town wall segment 8/9 with re-shaped crown in March 2012 (VAR. 1).

**PROPOSED WORK for 2013:**

Cleaning of wall segments.
Re-plastering of segment 8/9 including towers 8 and 9.

Consolidation of wall segment 17/18, State of Conservation Record: Nov. 2009 (Photo-Survey), planned for spring 2013

Works should follow ***fiches techniques.*** The fiches needed for the proposed work are are highlighted in **bold.**

**Fiche No. 1 Health & Safety instructions**
**Fiche No. 2 Building materials**
- **2.1 Materials to use for consolidation work**

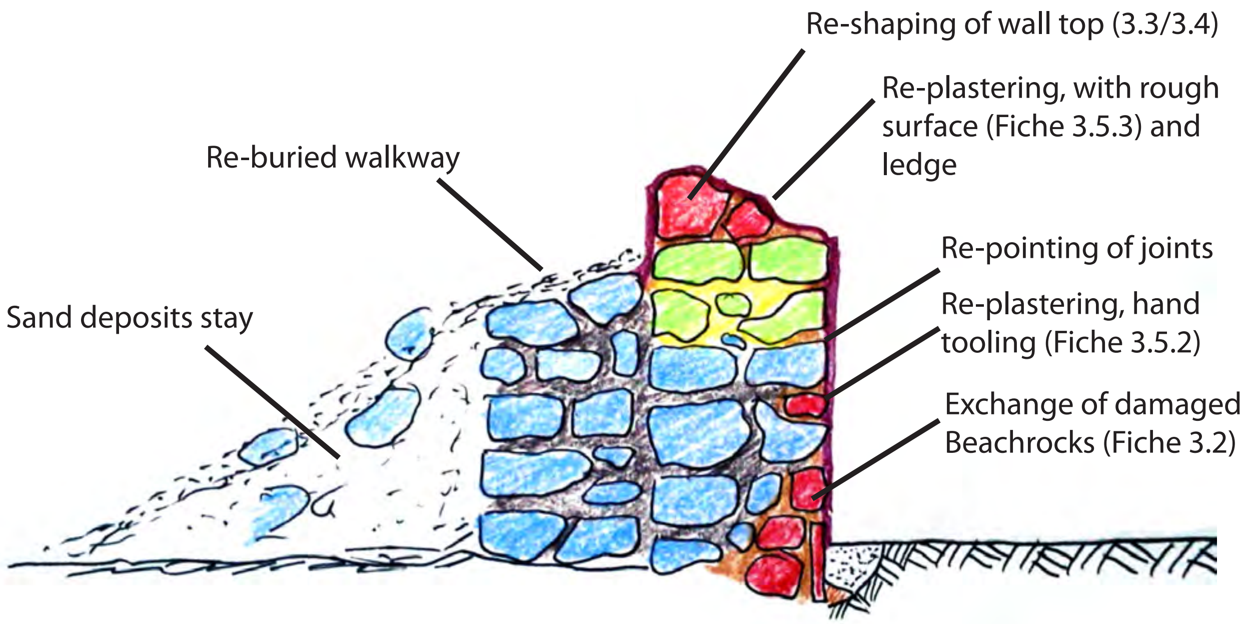
**Fiche No. 3 Wall consolidation**
- **3.1 Preparation and inital works**
- **3.2 Wall foundations**
- **3.3 Structural rebuilding**
- **3.4 Reconstruction**
- **3.5 Plaster works**
- **3.5.1 Smooth surface**
- **3.5.2 Hand tooling**
- **3.5.3 Rough surface**
- **3.5.4 Repairs**

Fiche No. 4 Consolidation and Stabilisation of Plasters
- 4.1 Consolidation of plaster surfaces
- 4.2 Fixing of loose plaster pieces/parts
- 4.3 Cementing of cracks
- 4.4 Notes

Fiche No. 5 Protection of architectural remains
- General guideline
- 5.1 Backfill
- **5.2 Stabilisation & Protection**

Fiche No.6 Monitoring
- **6.1 State of Conservation**
- 6.2 Climate data
- **6.3 Monitoring (Site journal)**
- 6.4 Indicators and Periodicity

GENERAL CONSERVATION CONCEPT

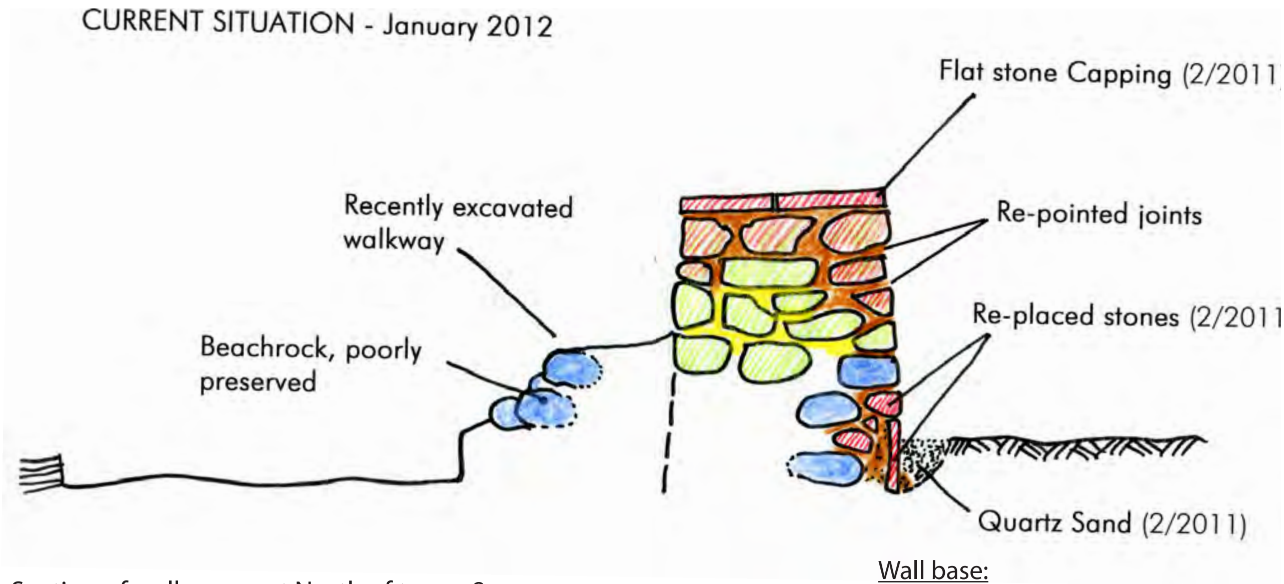



VAR. 2

Town wall segment at tower 4012 (ZUEP04) in March 2012 (VAR. 2).

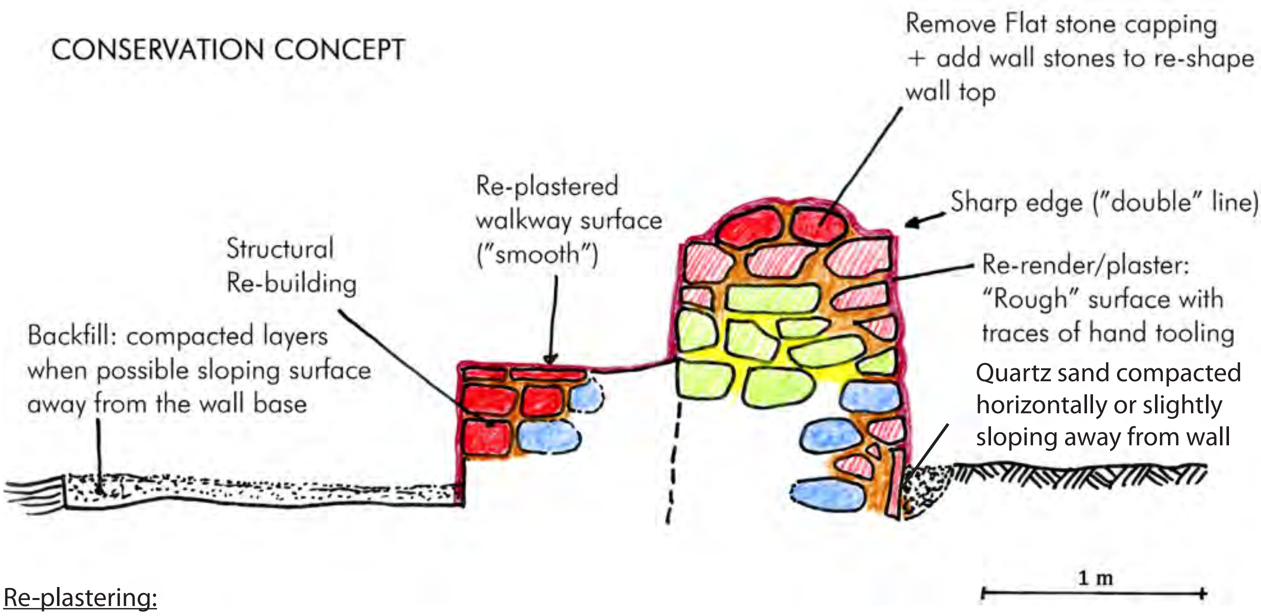
# CONSERVATION CONCEPT:

## TOWN WALL with exposed walkway, e.g. TOWER 8 / EP10

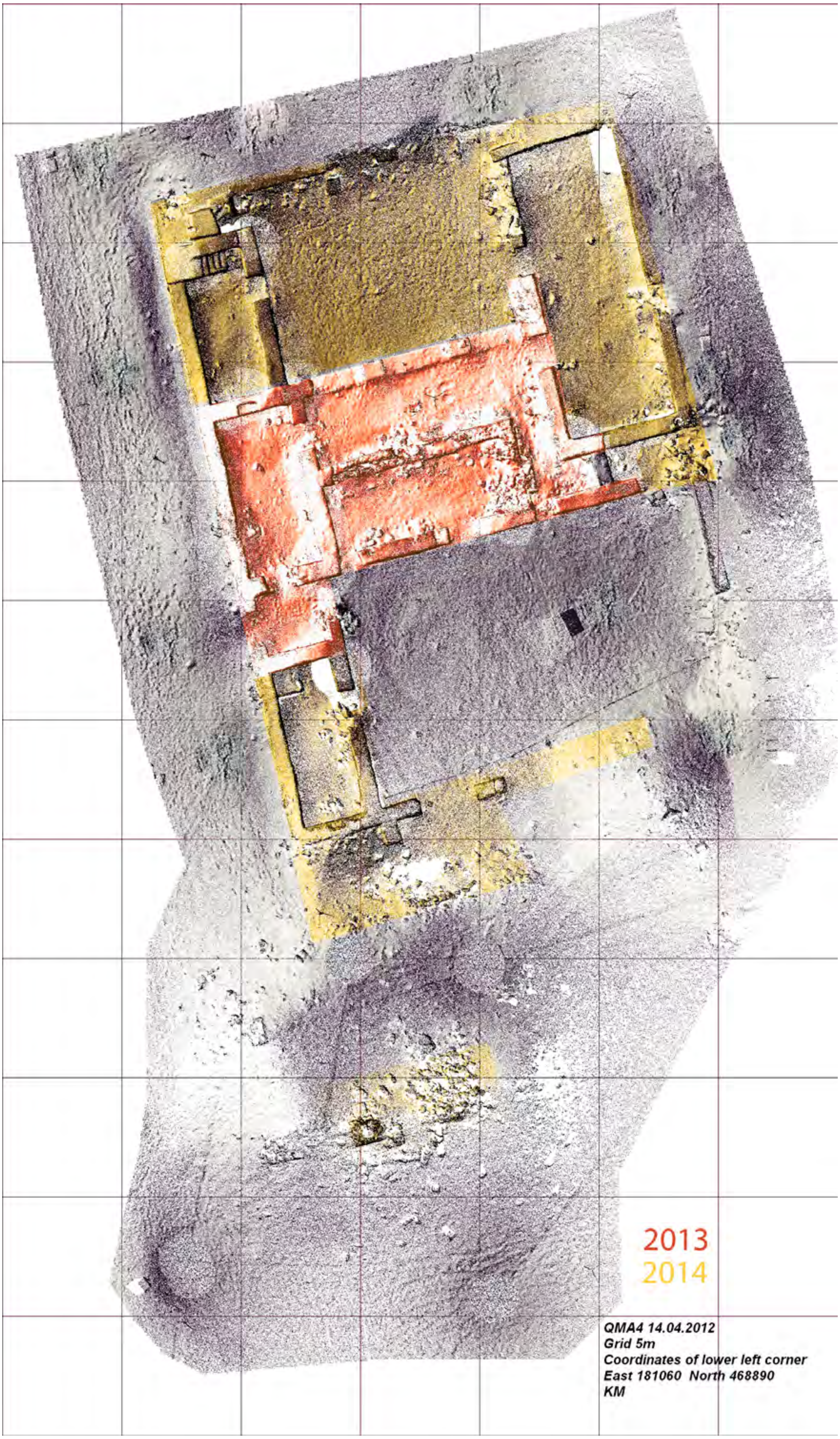



Section of wall segment North of tower 8

Wall base:
Soft Beachrock is in a poor state; Deterioration & Disintegration of Beachrock components!




Re-plastering:
"Rough" surface (wall top) and with traces of hand tooling (wall face); sharp edge (double-line) between wall top and wall face; edged corners


2013
2014
QMA4 14.04.2012
Grid 5m
Coordinates of lower left corner
East 181060 North 468890
KM

# APP.12.3 CONSERVATION SCHEME
# FORTIFIED COMPOUND QMA4

**PROPOSED WORK for 2013:**

Cleaning of area
Stabilisation and Protection of walls endangered to collapse

Consolidation of walls and wall plasters in Rooms R.004, R.005, R.006, R.007, and R.008.

State of Conservation Record: Nov. 2009 (Photo-Survey) and April 2012 (3D-Laserscan).

Works should follow ***fiches techniques.***
The fiches needed for the proposed work are are highlighted in **bold.**

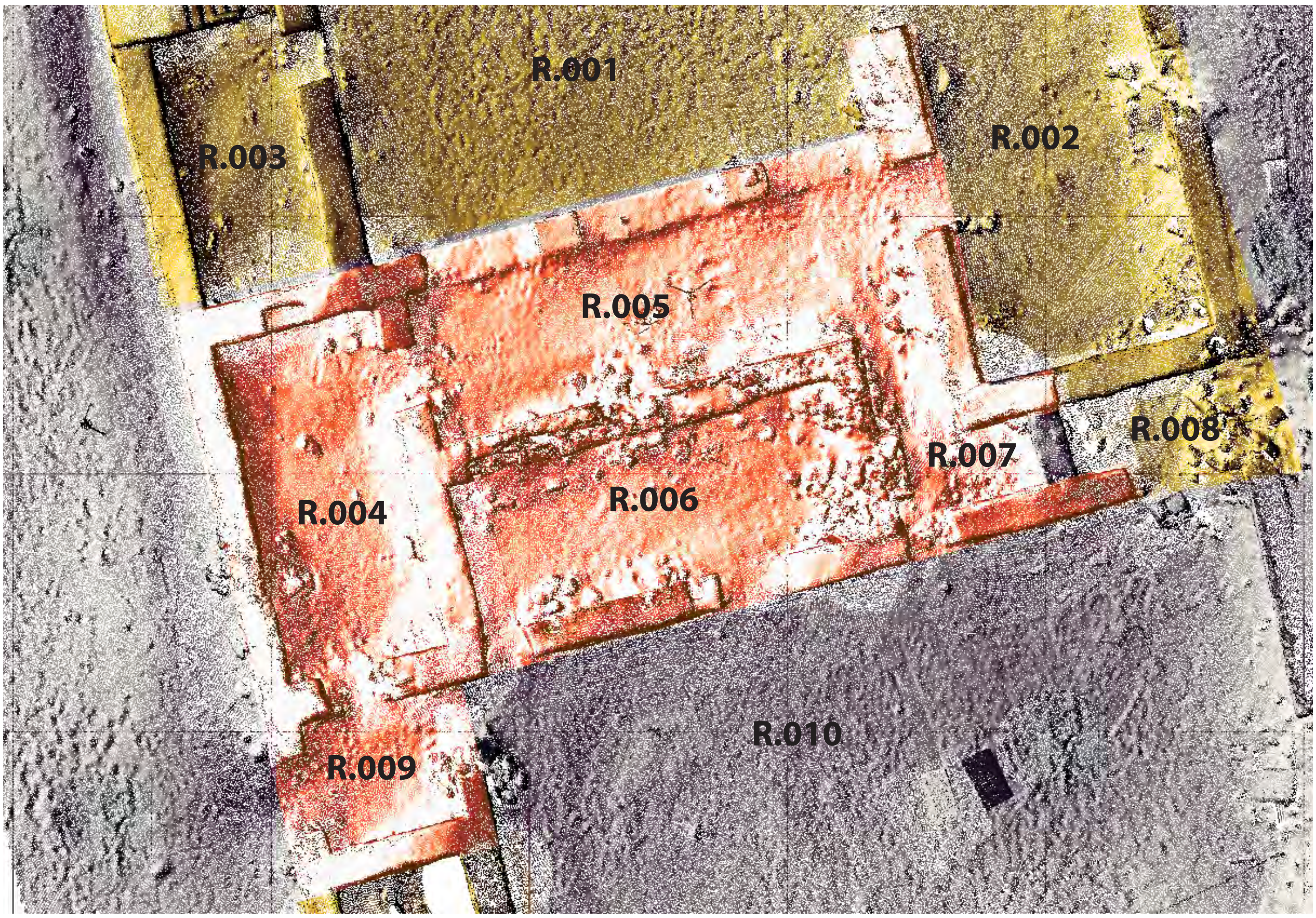
**Fiche No. 1 Health & Safety instructions**
**Fiche No. 2 Building materials**
- **2.1 Materials to use for consolidation work**

**Fiche No. 3 Wall consolidation**
- **3.1 Preparation and inital works**
- 3.2 Wall foundations
- **3.3 Structural rebuilding**
- **3.4 Reconstruction**
- **3.5 Plaster works**
- **3.5.1 Smooth surface**
- 3.5.2 Hand tooling
- **3.5.3 Rough surface**
- **3.5.4 Repairs**

**Fiche No. 4 Consolidation and Stabilisation of Plasters**
- **4.1 Consolidation of plaster surfaces**
- **4.2 Fixing of loose plaster pieces/parts**
- **4.3 Cementing of cracks**
- **4.4 Notes**

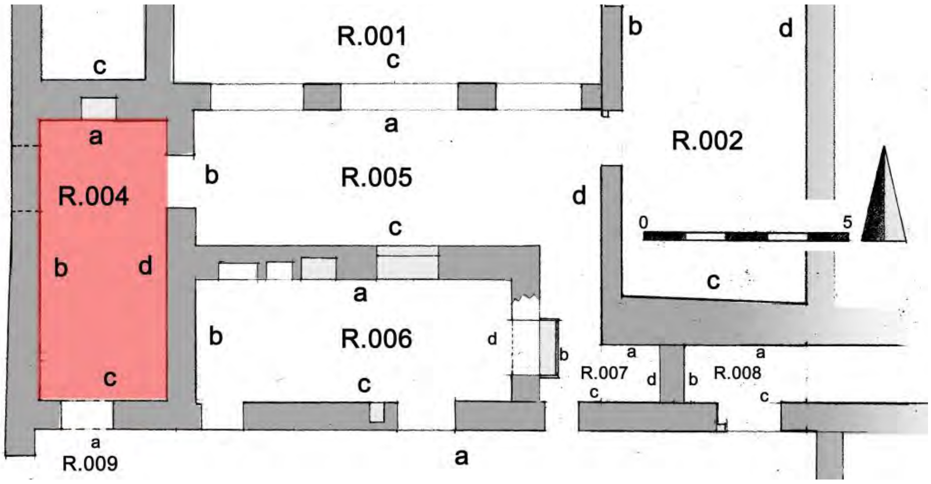
Fiche No. 5 Protection of architectural remains
- General guideline
- **5.1 Backfill**
- **5.2 Stabilisation & Protection**

Fiche No.6 Monitoring
- 6.1 State of Conservation
- 6.2 Climate data
- **6.3 Monitoring (Site journal)**
- 6.4 Indicators and Periodicity



# CASE STUDY QMA4_R.004

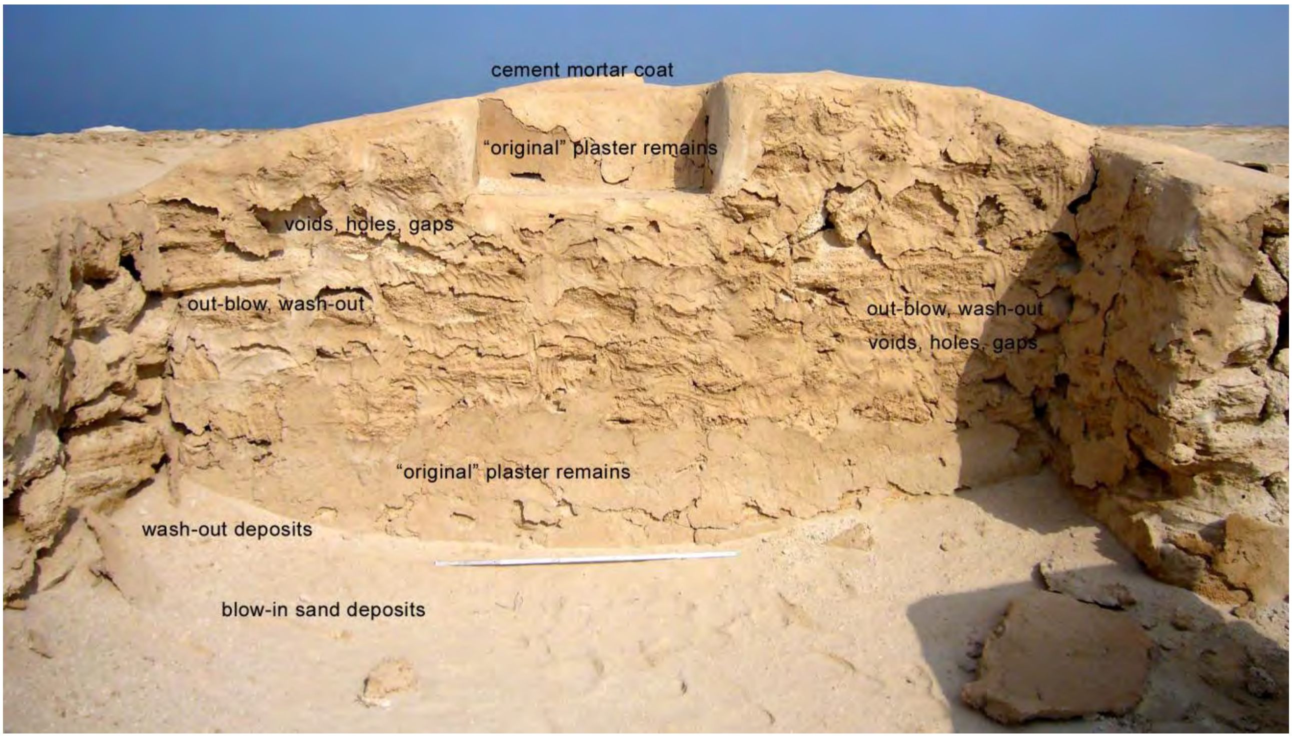
| | | | |
|---|---|---|---|
| ***Al Zubarah*** | Inventory - State of Preservation | November | 2009 |
| QMA 4 | Fortified Compound | Date: 18.11.2009 | |
| **R.004** | | | |




| **Description** (2009) | **Consolidation/Conservation suggestions** |
|---|---|
| *Measurements*: 6,80m x 3,10m. 21,08m². *Context*: Connected with R.005 and R.009. Features: Blocked door to exterior area in the west (street?); Niche in wall a. Floor is covered by deposits of blow-in sand and disintegrated building materials (beach rock components as well as sand). Relatively high concentration of salt. Fragile plaster remains at wall c and d which will be difficult to keep. | **Proposal 2012**: Consolidation of walls, including re-pointing of joints and replacing of wall stones at the wall base if necessary. Taking off cement capping and re-shaping of wall tops. Re-plastering with smooth surface showing some traces of trowel tooling. Removal of deposits down to floor level and protection of floor according to manual. |

State of Conservation - R.004_wall a

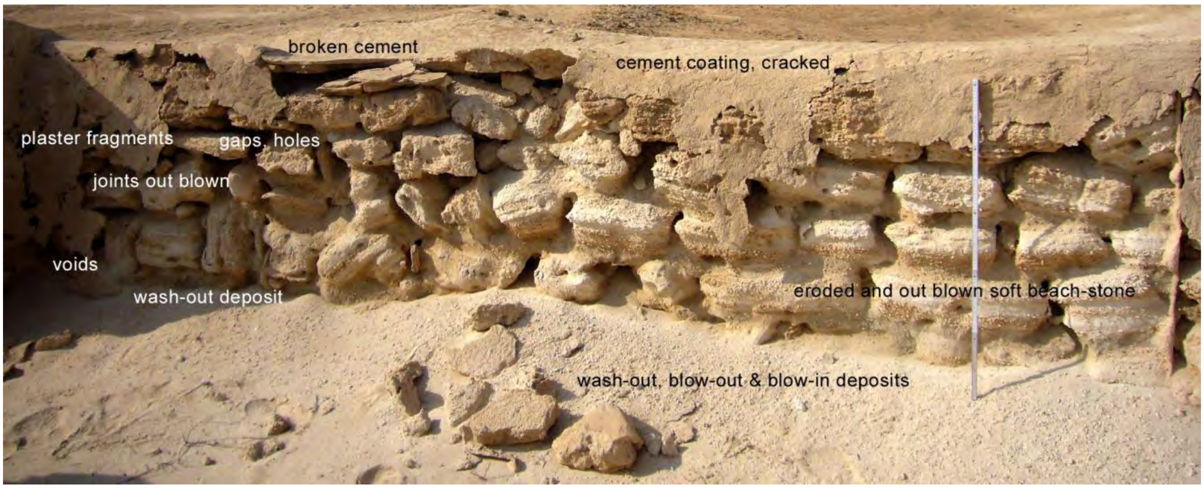
| | | | |
|---|---|---|---|
| ***Al Zubarah*** | Inventory - State of Preservation | November | 2009 |
| QMA 4 | Fortified Compound | Date: 18.11.2009 | |
| **R.004** | **Wall a** | | |

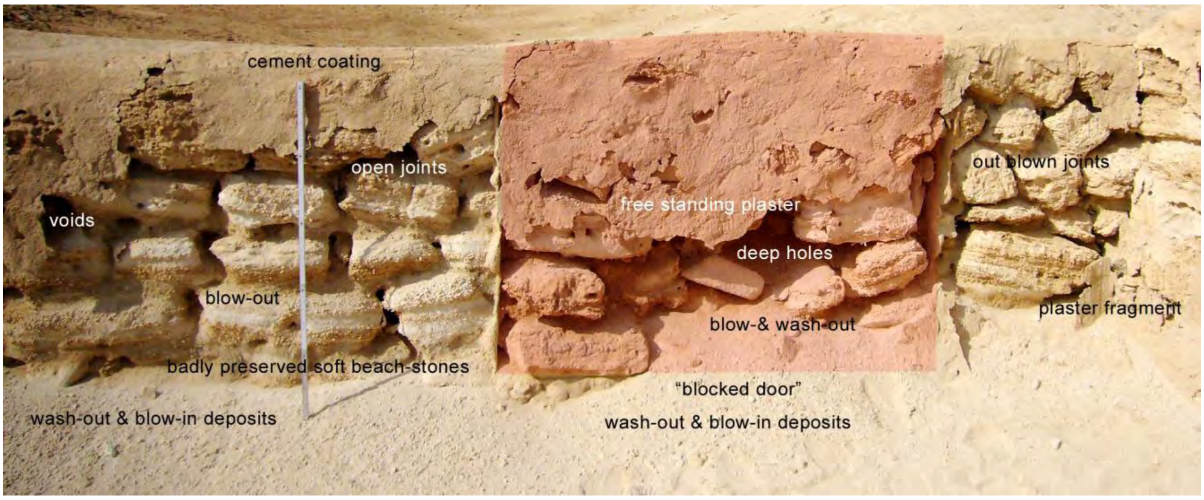



| **Wall a** | |
|---|---|
| **Description** | **Consolidation/Conservation suggestions** |
| Niche: b:82cm, t:48cm, UK 1,25m<br>Anhydrite plaster in lower part of the wall preserved. Hard cement capping, cement mortar between beach rock stones.<br>Voids, gaps, holes, out-blow, wash-out in wall structure.<br>At wall base blow-in sand deposits and wash-out accumulations of building material debris. | 2012: Remove deposits in front of wall base;<br>Remove cement capping and mortar;<br>Consolidation of historic plaster remains;<br>consolidation of wall structure; Re-shaping wall top and re-plastering according to manual |

## State of Conservation - R.004_wall b

| | | | |
|---|---|---|---|
| ***Al Zubarah*** | Inventory - State of Preservation | November | 2009 |
| QMA 4 | Fortified Compound | Date: 18.11.2009 | |
| **R.004** | **Wall b** | | |




| **Wall b** | |
|---|---|
| **Description** | **Consolidation/Conservation suggestions** |
| Cement coat on wall top: Crackling.<br>Beach stone (Ag) is badly preserved, mostly eroded and effected by out-blow and wash-out processes.<br>Blocked door in northern half of the wall. The door reveal on both sides shows well preserved plaster remains!<br>Massive wash-out-, blow-in-deposits at wall bottom of sand and disintegrated building material components.<br>Only in southern corner some "original" plaster fragments preserved. | 2012: Removal of deposits down to floor level; Removal of cement capping and render; consolidation of wall structure; re-shaping of wall top - capturing door reveal of blocked door; Re-plastering according to scheme. |

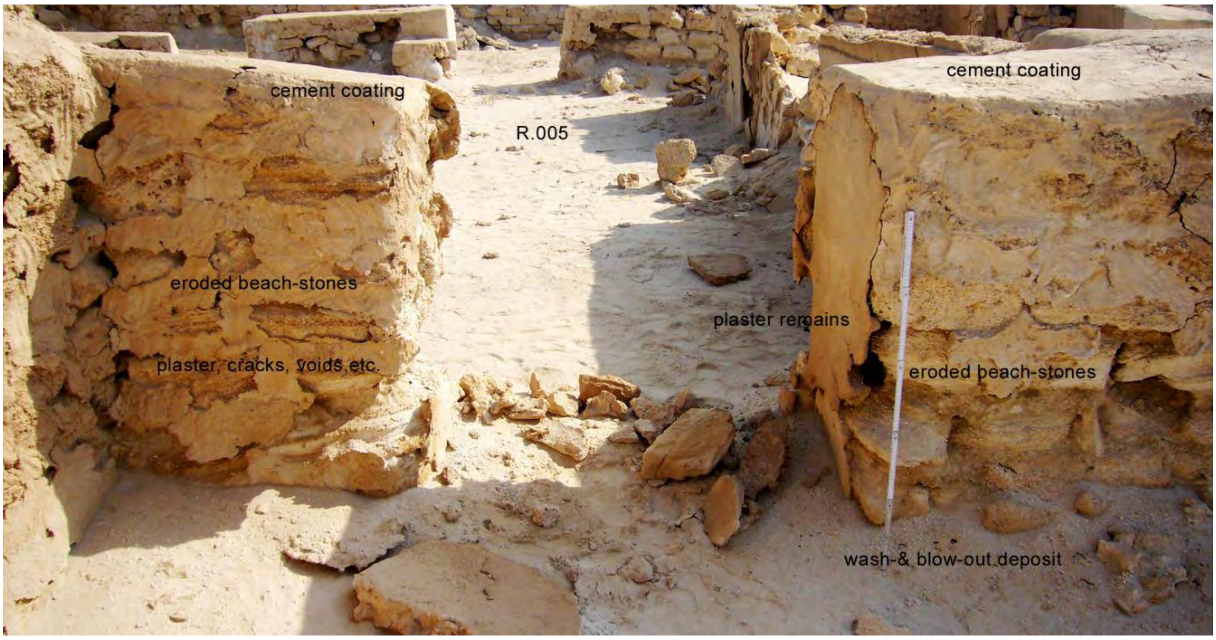
State of Conservation - R.004_wall c

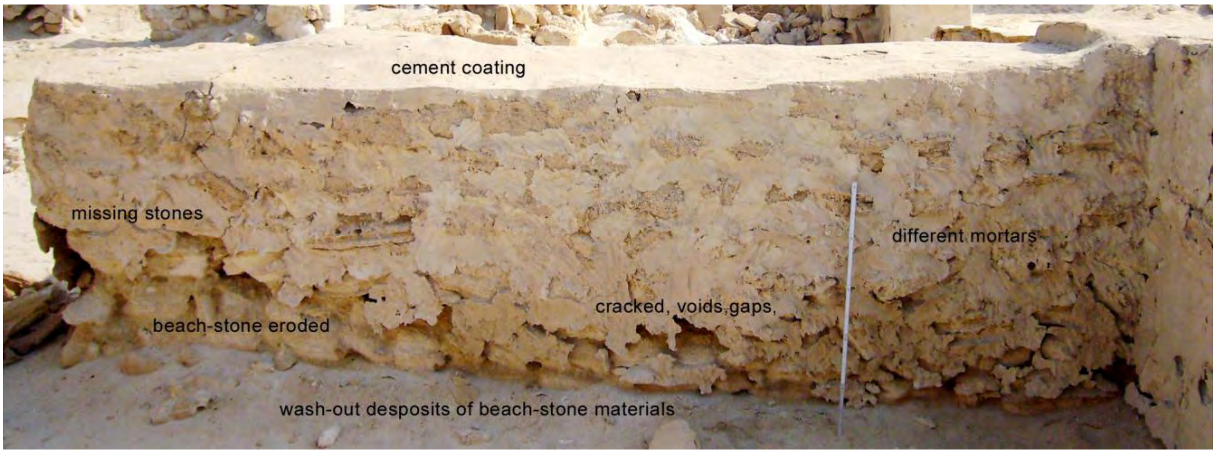
| | | | |
|---|---|---|---|
| ***Al Zubarah*** | Inventory - State of Preservation | November | 2009 |
| QMA 4 | Fortified Compound | Date: 18.11.2009 | |
| **R.004** | **Wall c** | | |


| **Wall c** | |
|---|---|
| **Description** | **Consolidation/Conservation suggestions** |
| Cement coat on wall top and upper 1/3 of wall face is crackling.<br>Beach stone material is in a very poor state and heavily effected by aeolian and fluvial erosion processes. Wall structure starts to collapse.<br>Massive deposits of disintegrated building material debris at wall base.<br>In lower half of the wall historic plaster fragments preserved.<br>It is unclear if the wall opening is a result of the 1980s excavation and consolidation work or if it is a historical context. | 2012: Removal of deposits; Sorting of wall stones and plaster remains; Removal of cement capping and render; consolidation of wall structure; consolidation of historic plaster remains; re-plastering. |

## State of Conservation - R.004_wall d

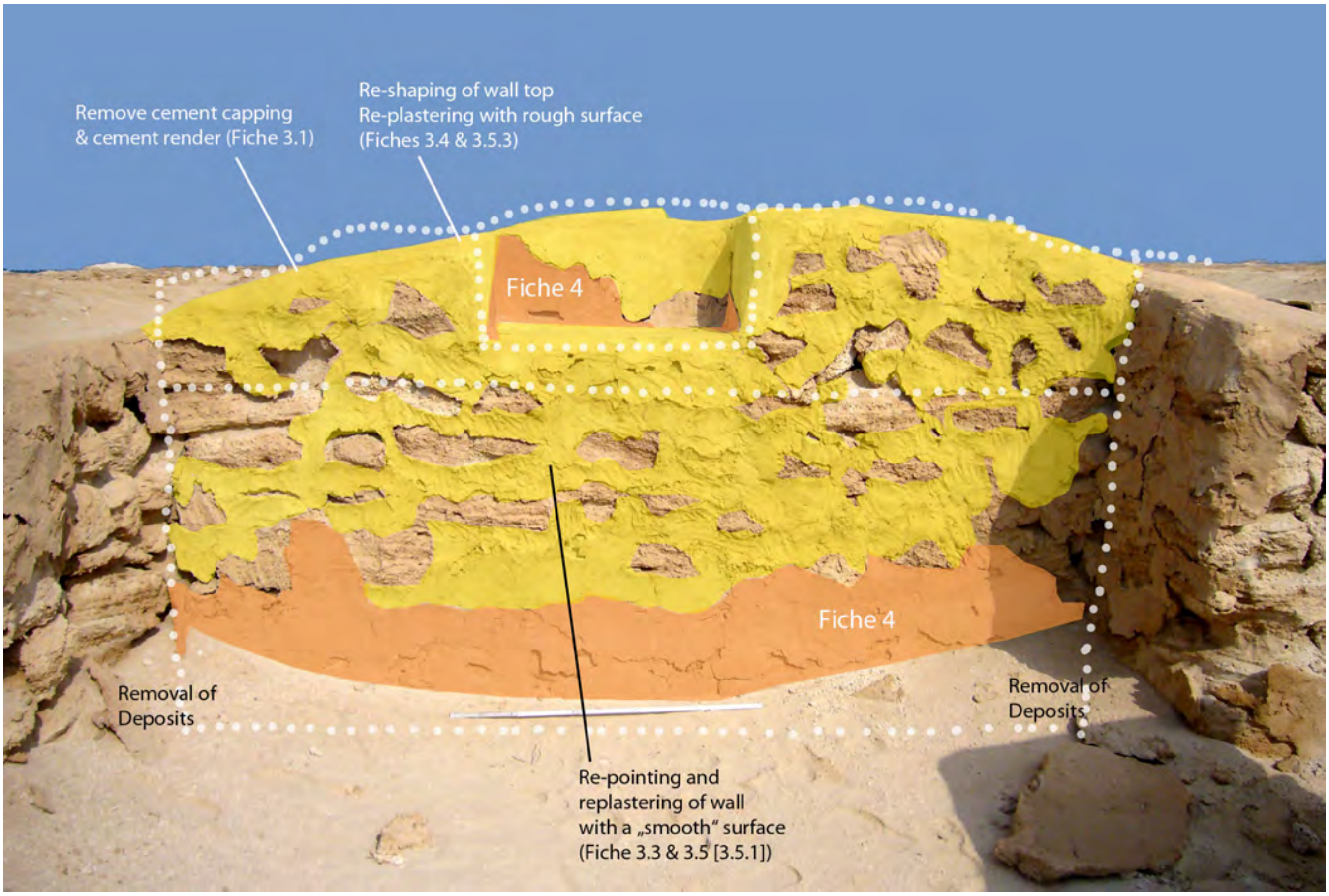
| | | | |
|---|---|---|---|
| ***Al Zubarah*** | Inventory - State of Preservation | November | 2009 |
| QMA 4 | Fortified Compound | Date: 18.11.2009 | |
| **R.004** | **Wall d** | | |



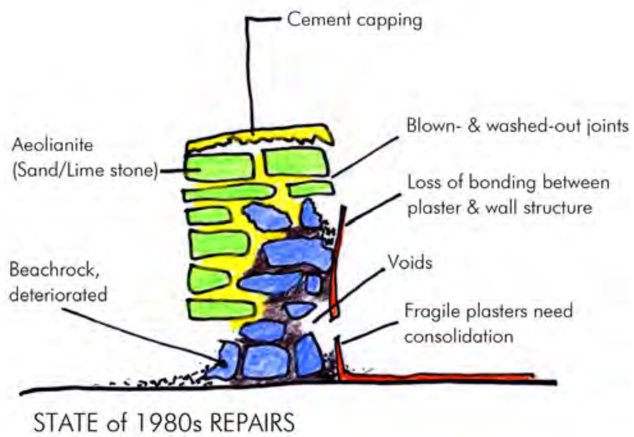

| **Wall d** | |
|---|---|
| **Description** | **Consolidation/Conservation suggestions** |
| Beach stone-wall with mud/soil-, anhydrite- & cement-mortar. Cement coating, in lower parts also historic plaster fragments are preserved. Substantial plaster remains in door reveal and in front of the wall.<br>Beach stone is in a poor state especially at the wall base. Heavily weathered wall stones. Deposits of disintegrated building material debris and blown-in soil/sand. Wall opening (door) to R.005. Missing stones. Voids in the wall structure. | 2012: Remove deposits, Collect fallen plaster remains; Remove cement capping and render; Consolidation of wall structure and plaster remains (mainly at the door); Re-shaping of wall top and re-plastering. |

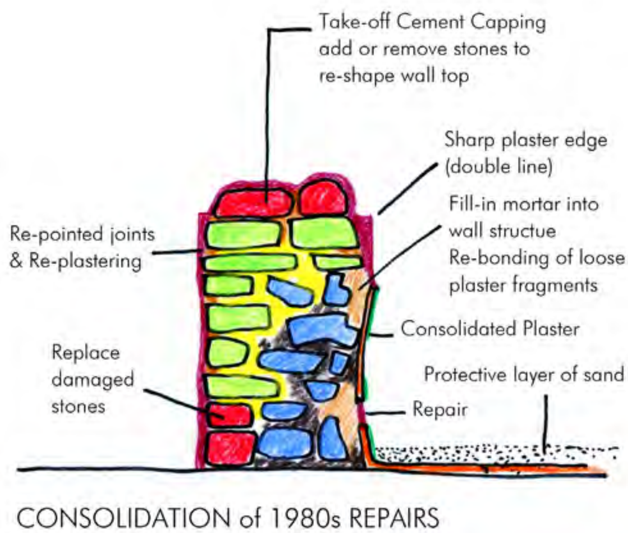
PROPOSED MEASURES and CONSERVATION CONCEPT - R.004_wall a



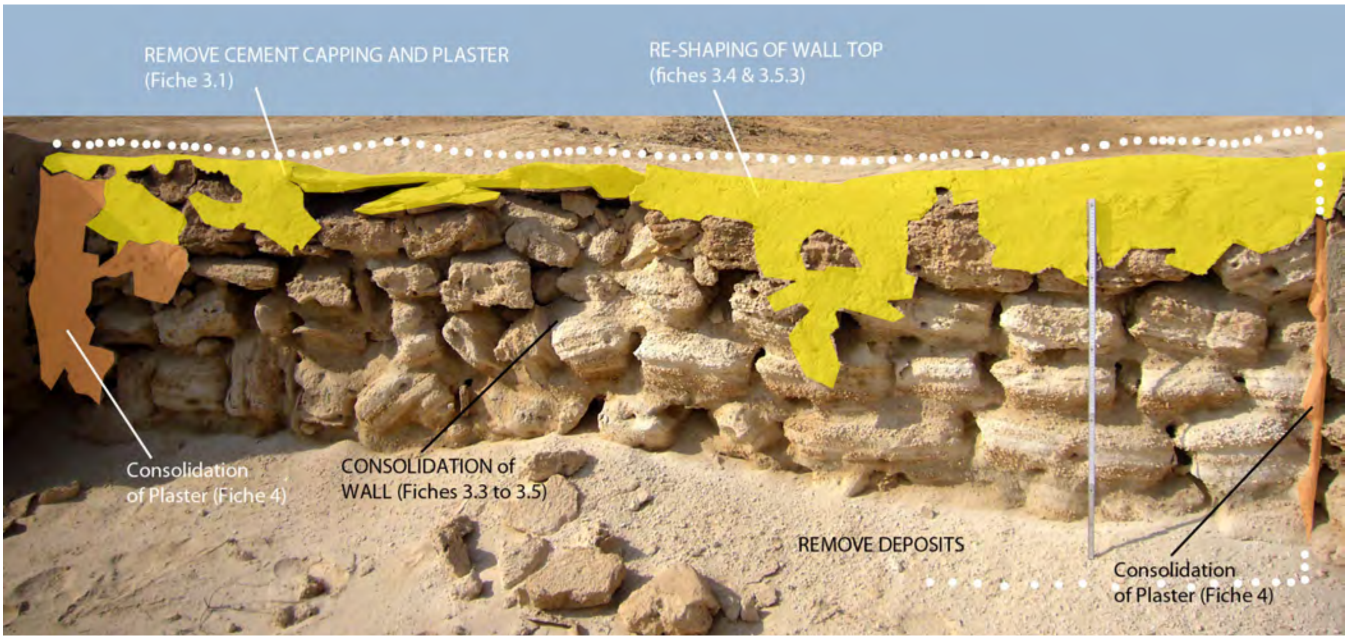

QMA 4_R.004 wall a; proposed conservation works

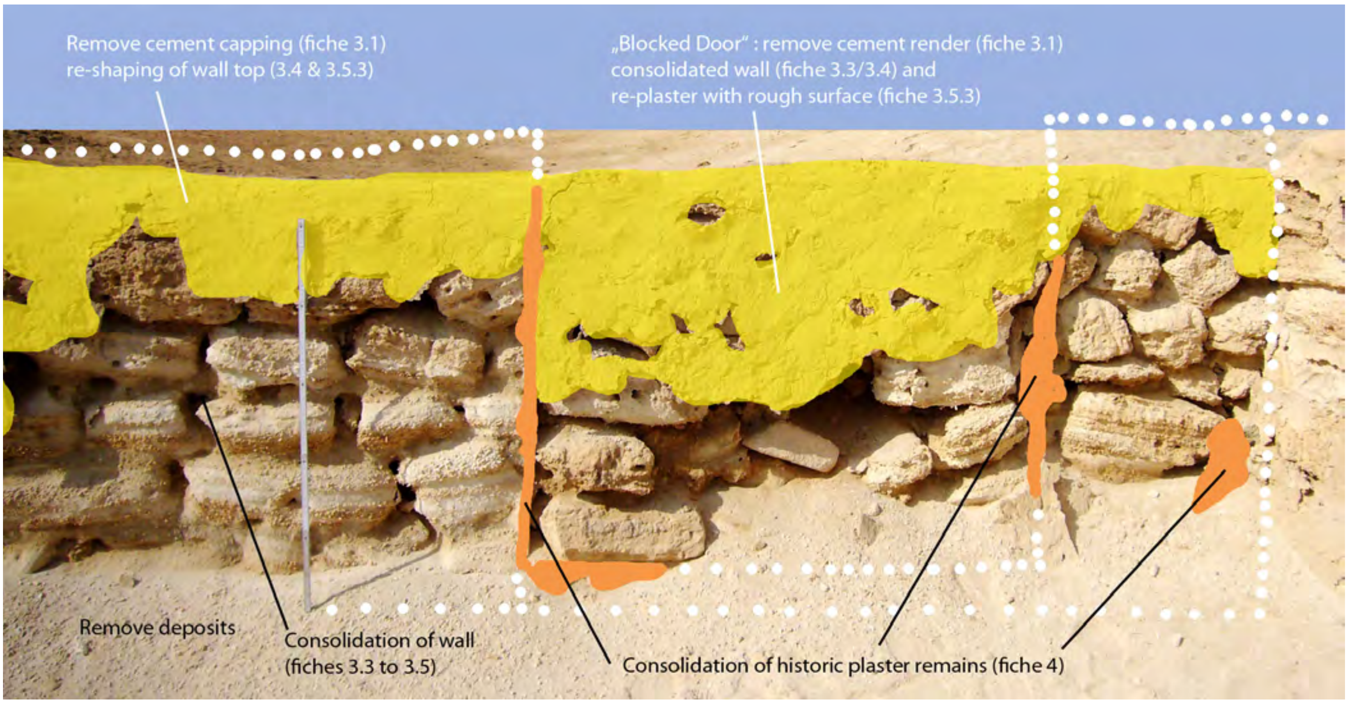
Design & Conservation principles



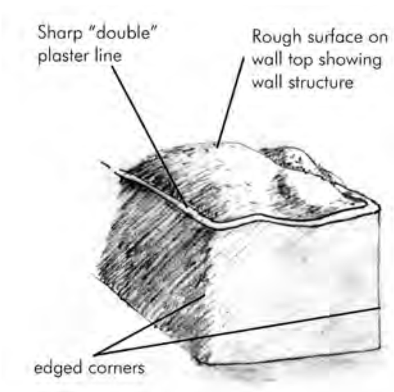



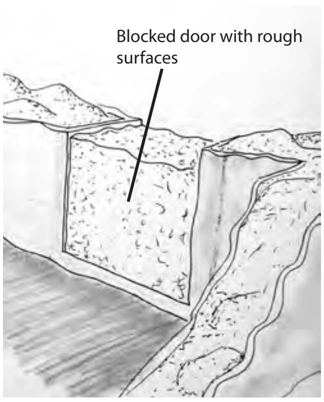
## PROPOSED MEASURES and CONSERVATION CONCEPT - R.004_wall b



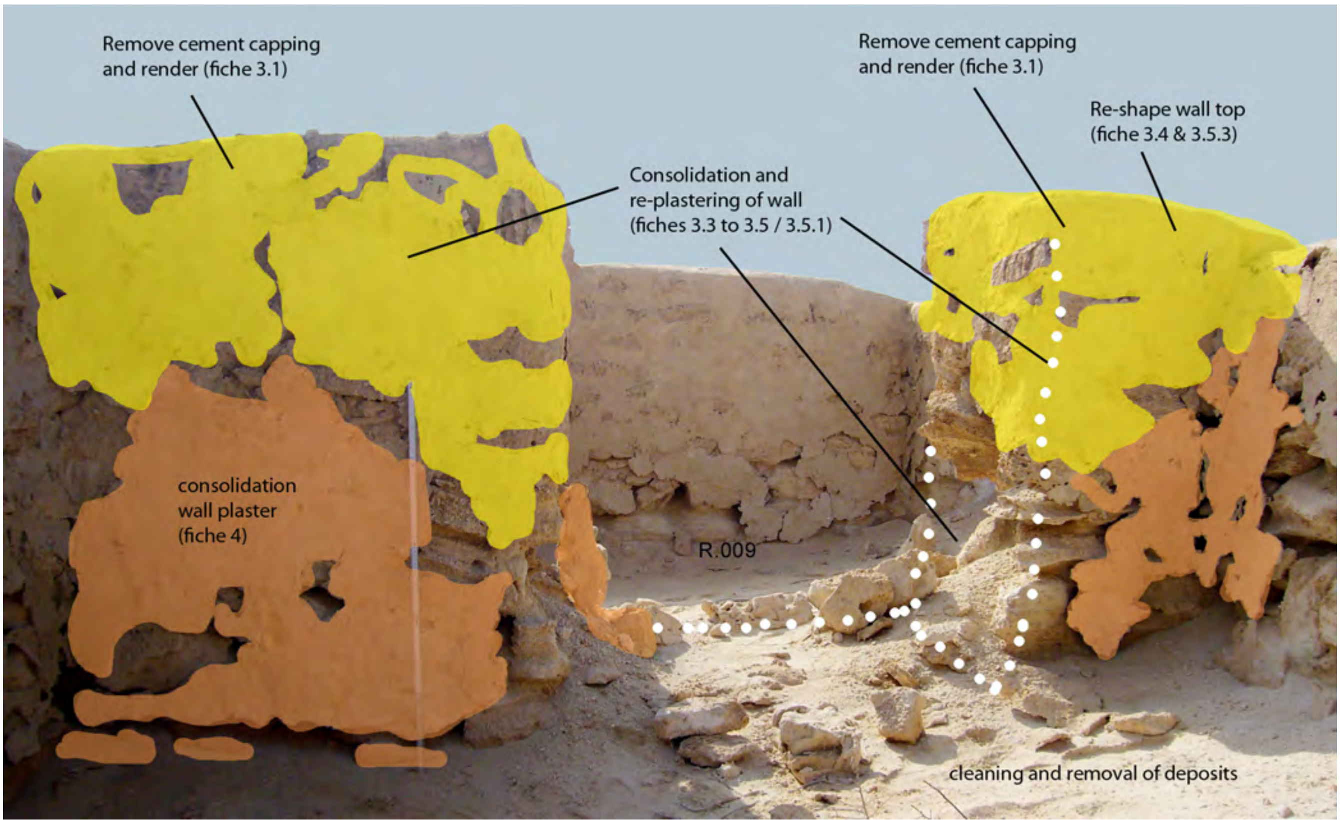

QMA 4_R.004 wall b; proposed conservation works




Design principles

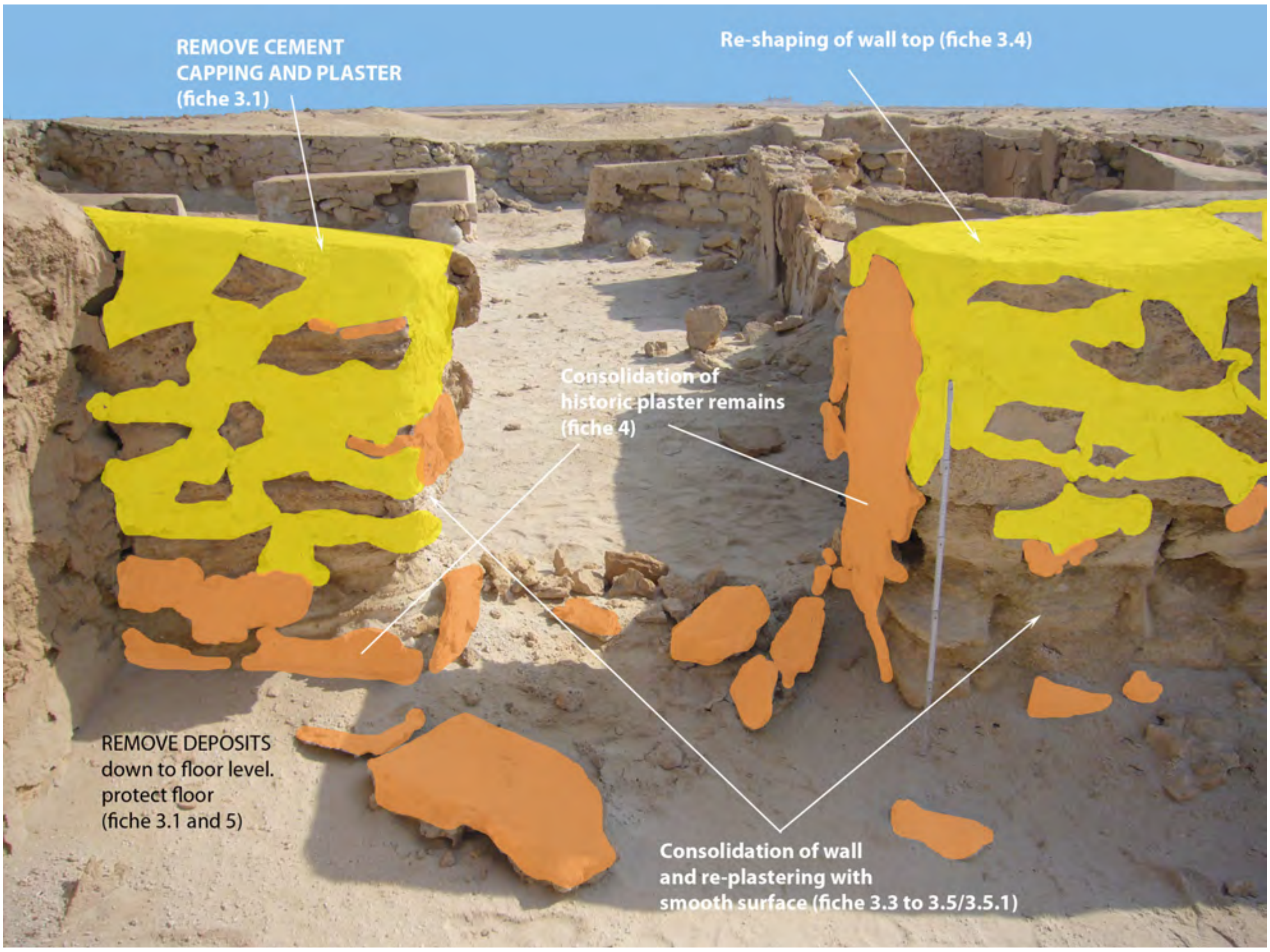
PROPOSED MEASURES and CONSERVATION CONCEPT - R.004_wall c

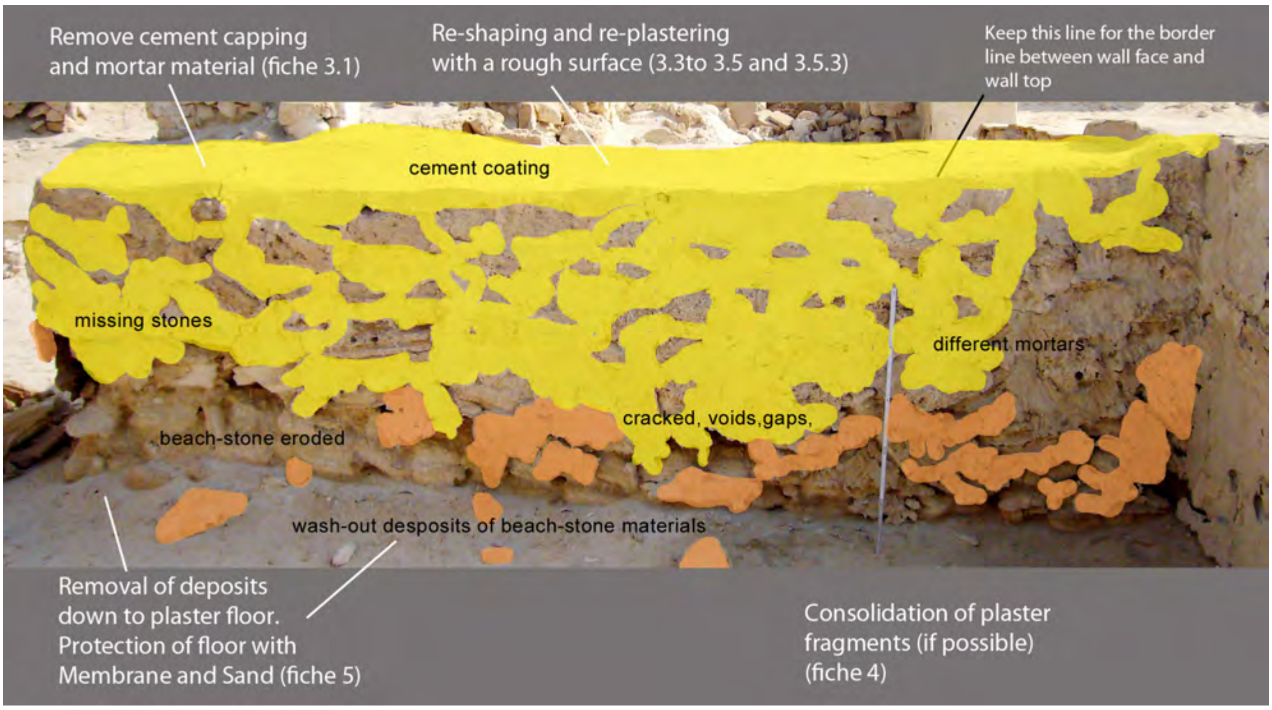



QMA 4_R.004 wall c; proposed conservation works

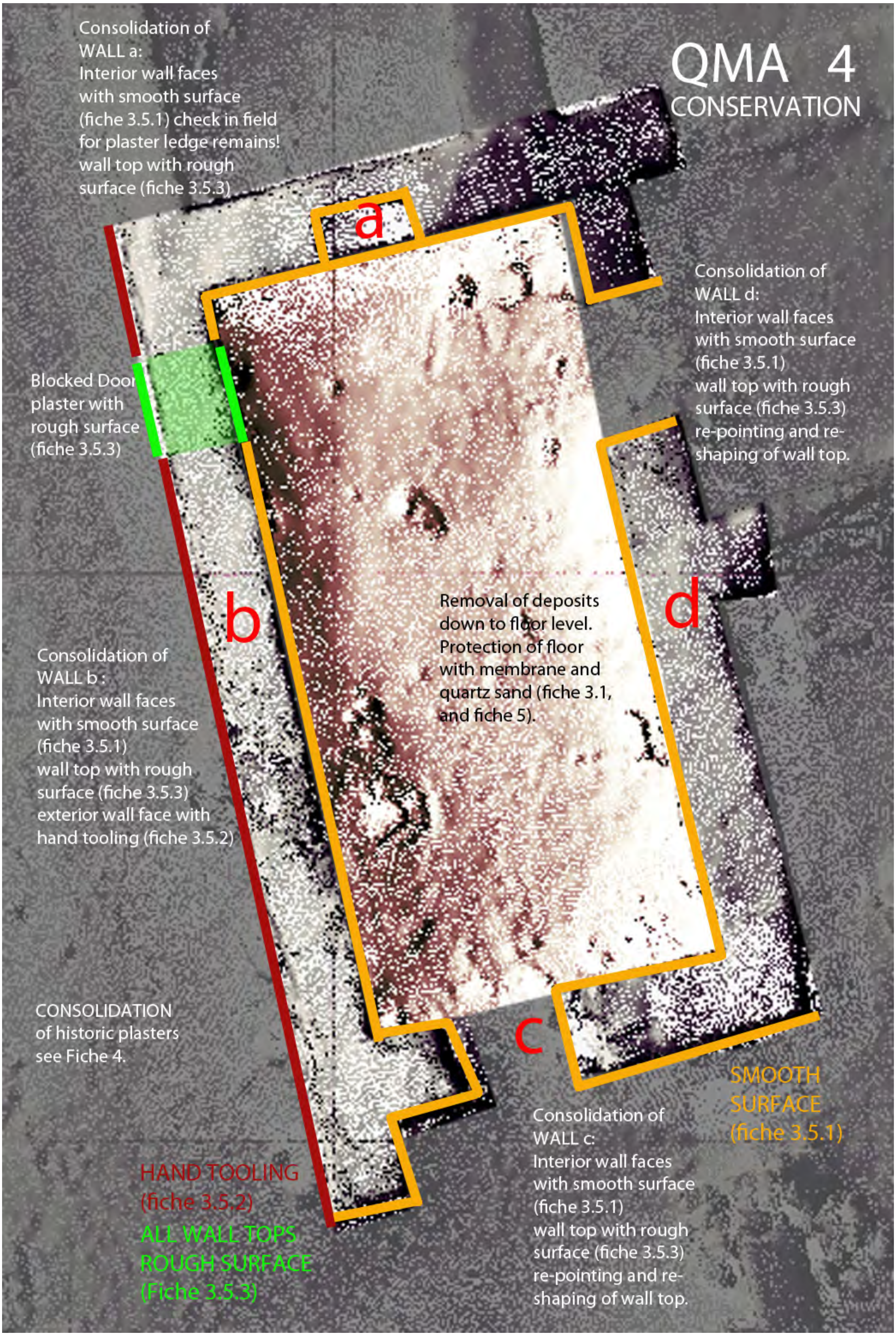
Comparable situation in the Palace (ZUEP04) after consolidation and re-plastering. Historic plaster remains were consolidated and integrated in the plaster surface.

PROPOSED MEASURES and CONSERVATION CONCEPT - R.004_wall d



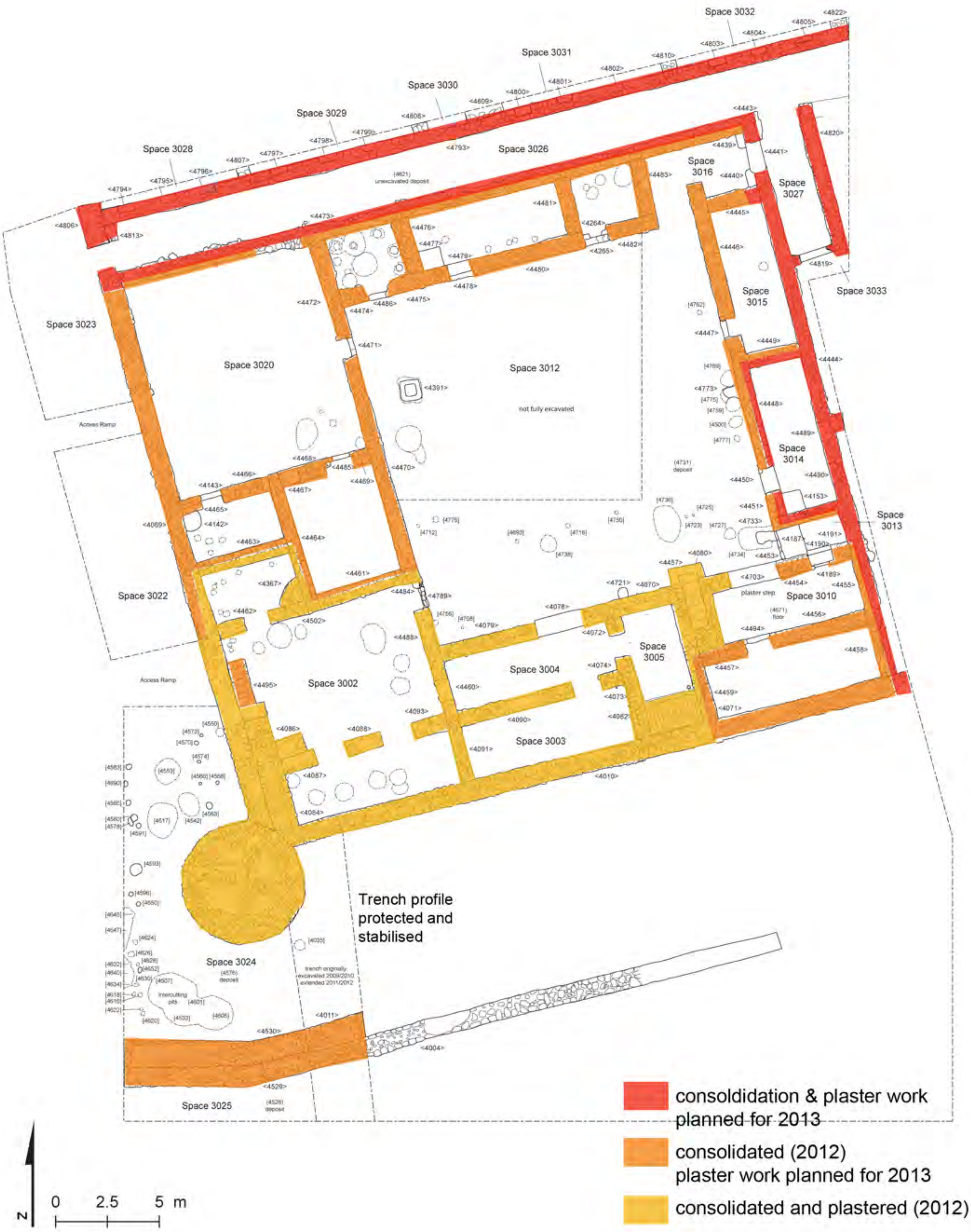



# APP.12.3 CONSERVATION SCHEME
# FORTIFIED COMPOUND QMA4



# APP.12.4 CONSERVATION SCHEME

## PALACE ZUEP04



# APP.12.4 CONSERVATION SCHEME

# PALACE ZUEP04

**PROPOSED WORK for 2013:**

De-backfill and removal of stabilisation material along walls etc. to prepare further excavation, documenation and initial consolidation work.

Re-plastering of walls initially consoldiated in 2012

Consolidation of walls and wall plasters

State of Conservation Record: March 2011 (Photo-Survey & 3D-Laserscan); December 2011/ January 2012 (Photo survey prior to work); April 2012 (3D-Laserscan).

Works should follow ***fiches techniques.***
The fiches needed for the proposed work are are highlighted in **bold.**

**Fiche No. 1 Health & Safety instructions**
**Fiche No. 2 Building materials**
- **2.1 Materials to use for consolidation work**

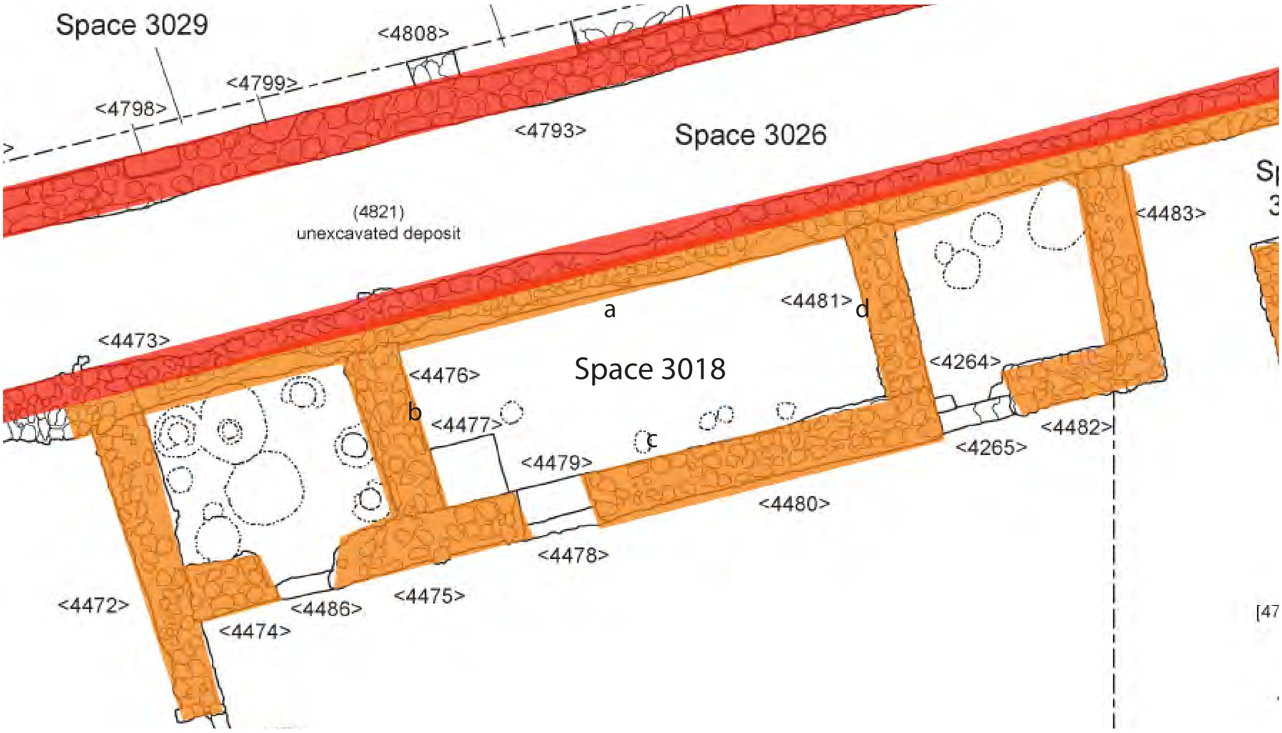
**Fiche No. 3 Wall consolidation**
- **3.1 Preparation and inital works**
- 3.2 Wall foundations
- **3.3 Structural rebuilding**
- **3.4 Reconstruction**
- **3.5 Plaster works**
- **3.5.1 Smooth surface**
- **3.5.2 Hand tooling**
- **3.5.3 Rough surface**
- **3.5.4 Repairs**

**Fiche No. 4 Consolidation and Stabilisation of Plasters**
- **4.1 Consolidation of plaster surfaces**
- **4.2 Fixing of loose plaster pieces/parts**
- **4.3 Cementing of cracks**
- **4.4 Notes**

**Fiche No. 5 Protection of architectural remains**
- General guideline
- **5.1 Backfill**
- **5.2 Stabilisation & Protection**

Fiche No.6 Monitoring
- 6.1 State of Conservation
- 6.2 Climate data
- **6.3 Monitoring (Site journal)**
- 6.4 Indicators and Periodicity

# CASE STUDY: Palace ZUEP04_Space 3018

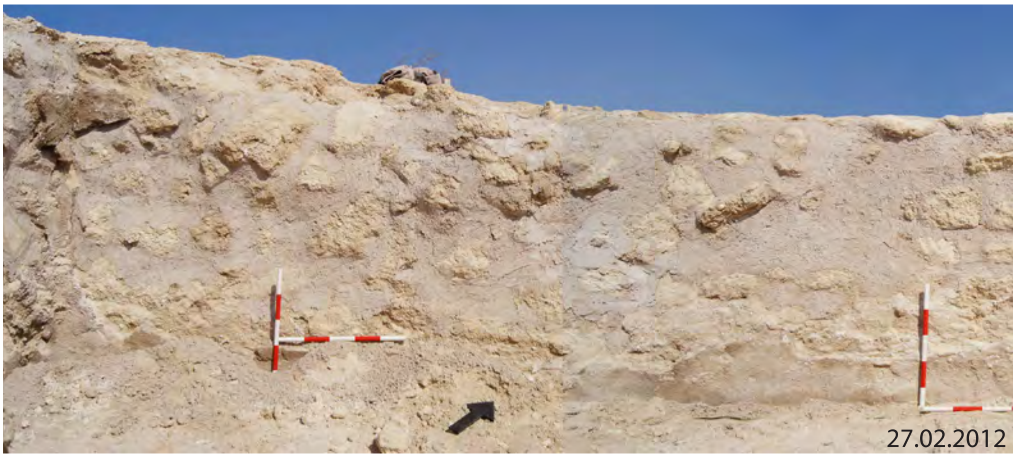


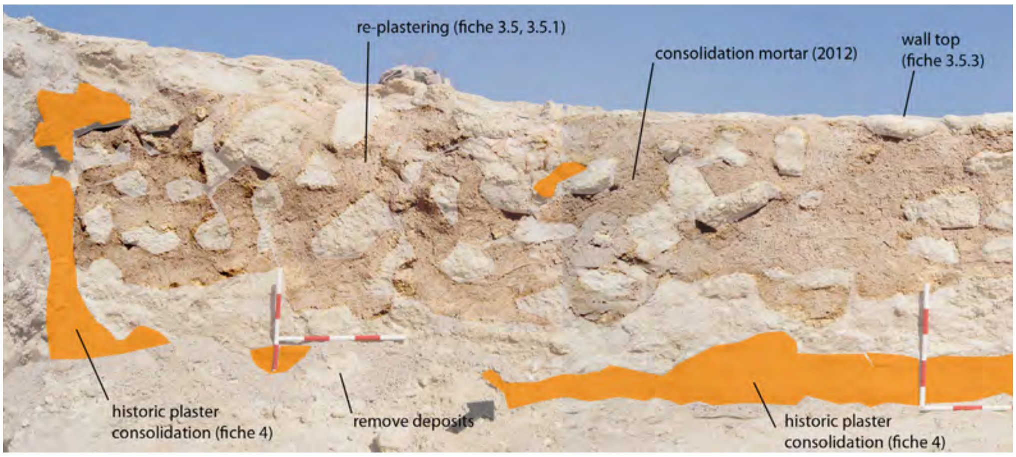

space 3018

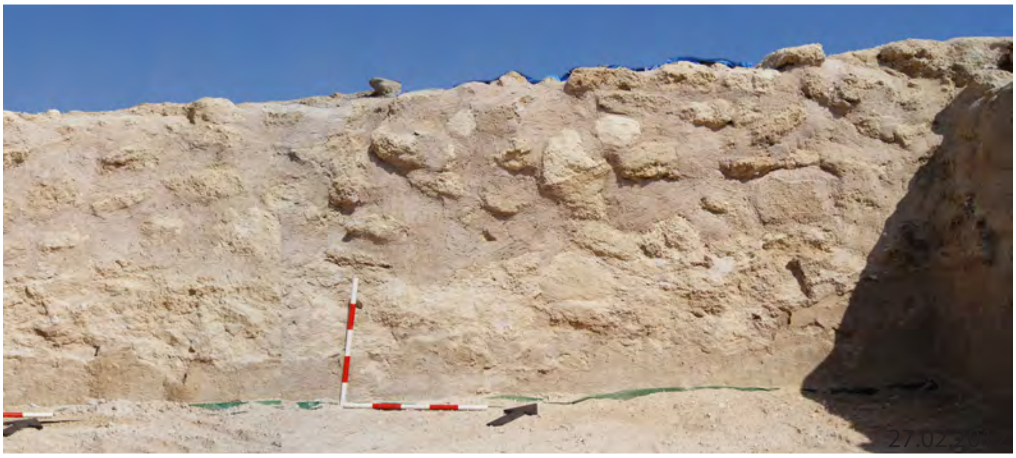

Consolidation example space 3005

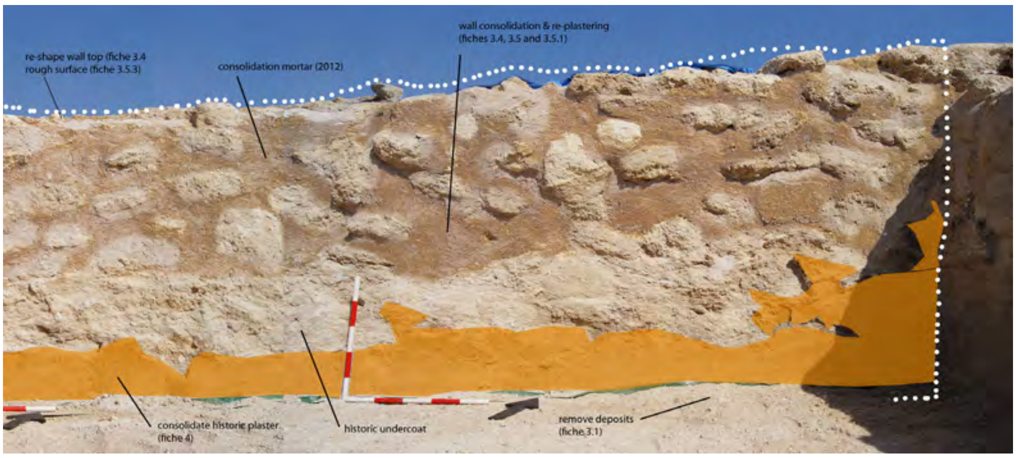

Consolidation example ZUEP04

PROPOSED MEASURES and CONSERVATION CONCEPT - Space 3018_wall a (4473)



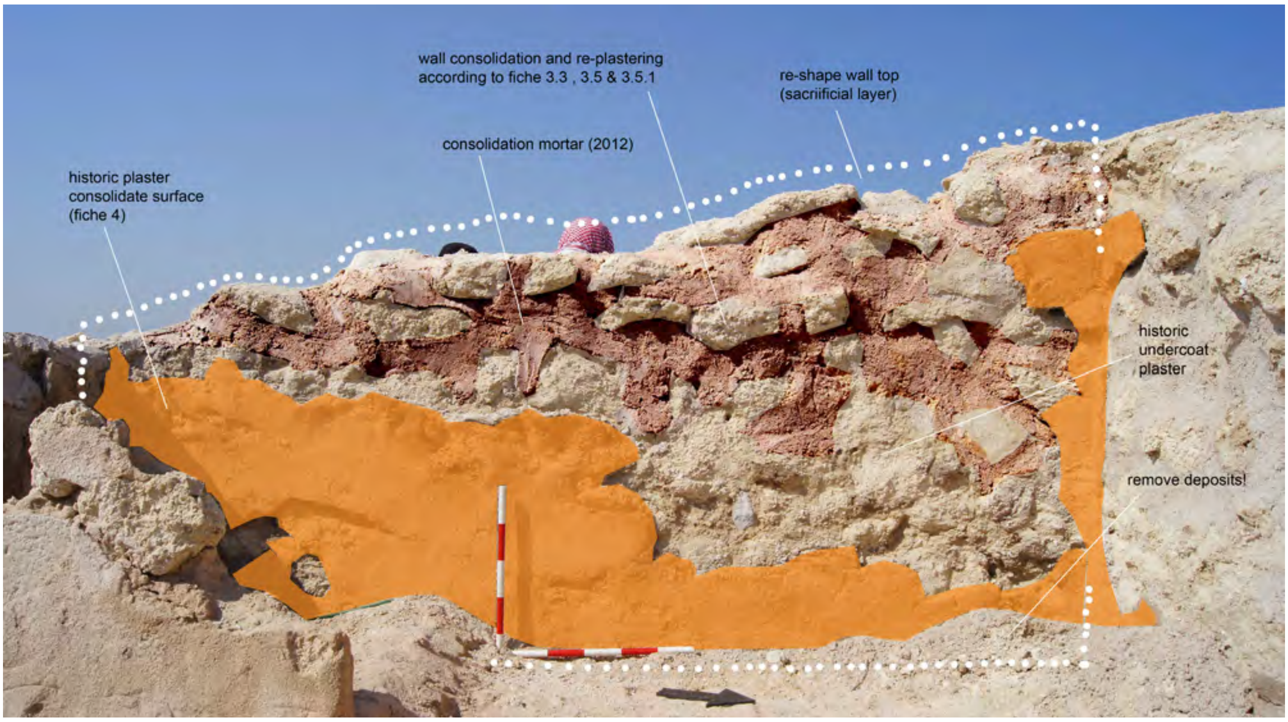





PROPOSED MEASURES and CONSERVATION CONCEPT - Space 3018_wall b (4476)

Wall 4476, state of conservation, February 27th, 2012

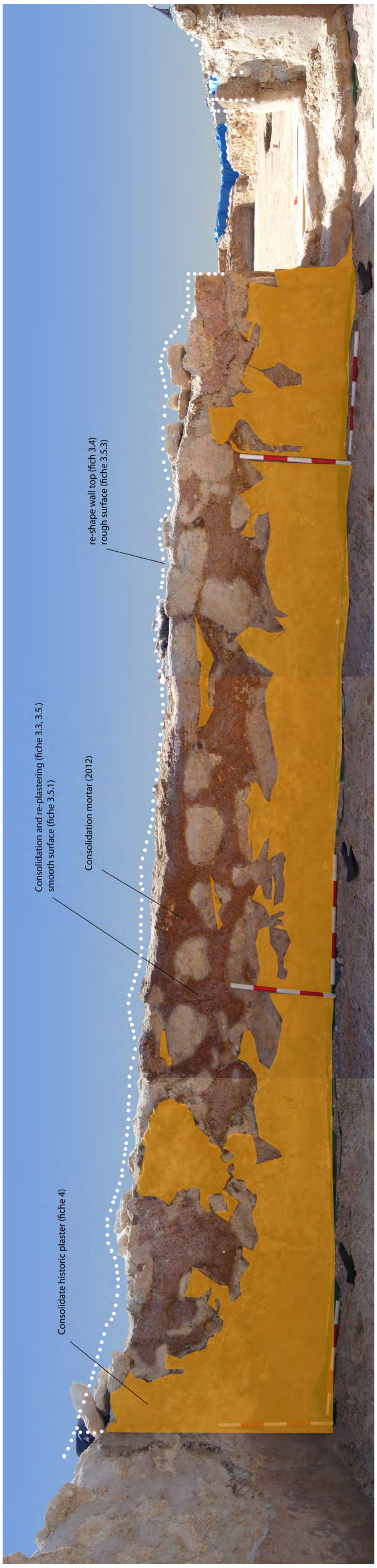



Wall 4476, mapped materials and planned measures

# APP.12.4 CONSERVATION SCHEME

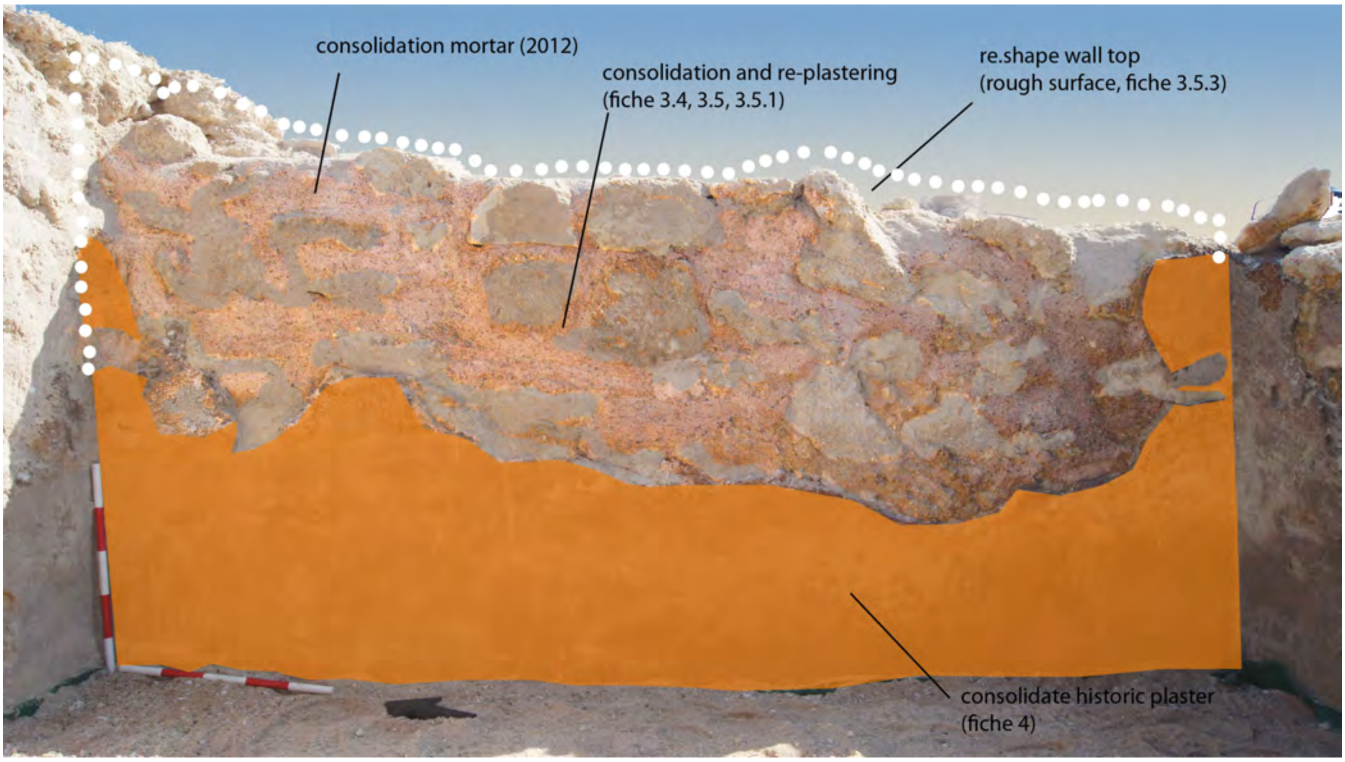
## PALACE ZUEP04

PROPOSED MEASURES and CONSERVATION CONCEPT - Space 3018_wall c (4480/4475)



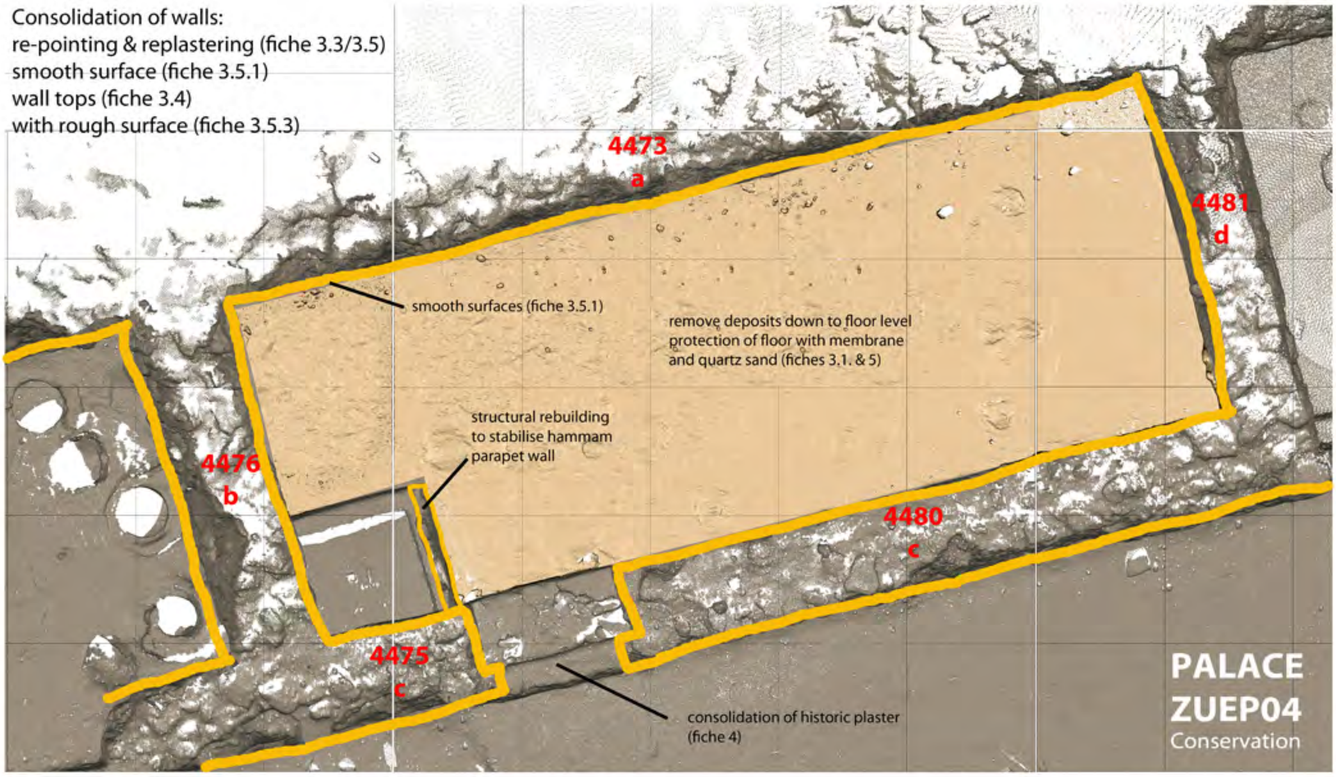
PROPOSED MEASURES and CONSERVATION CONCEPT - Space 3018_wall d (4481)

Wall 4481, state of conservation, February 27th, 2012



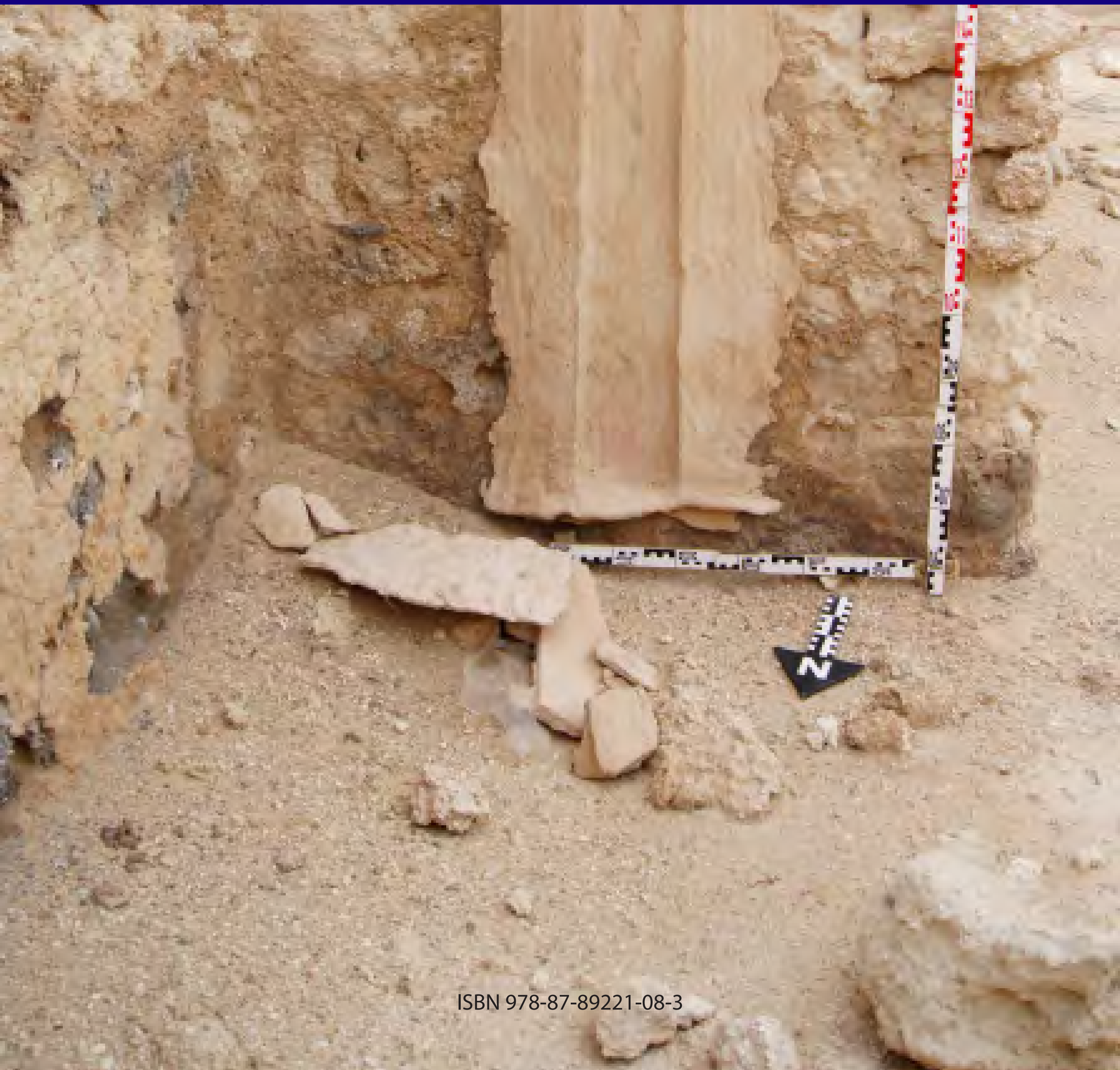

Wall 4481, mapped materials and planned measures

PROPOSED MEASURES and CONSERVATION CONCEPT - Space 3018



**The Conservation Handbook for Al Zubarah Archaeological Site brings together all the existing information on the site and includes information from site reports and archive material. It also makes the information more easily accessible to people involved in the conservation process.**

**The Handbook provides guidelines for the conservation and consolidation of architectural remains at Al Zubarah Archaeological site. It presents information on environmental conditions, building materials, weathering patterns, conservation concepts, and also fiches techniques providing practical instructions for the actual conservation work.**



ISBN 978-87-89221-08-3